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POPULATION DYNAMICS AND PARASITISM OF BRASSICA INSECT PESTS IN ZIMBABWE WITH EMPHASIS ON THE DIAMONDBACK MOTH, PLUTELLA XYLOSTELLA (L.) (LEPIDOPTERA: PLUTELLIDAE)

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POPULATION DYNAMICS AND PARASITISM OF BRASSICA INSECT PESTS IN ZIMBABWE, WITH EMPHASIS ON THE DIAMONDBACK MOTH, *PLUTELLA XYLOSTELLA* (L.) (LEPIDOPTERA: PLUTELLIDAE)

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ABSTRACT

The diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), is a major insect pest of brassicas in Zimbabwe. Field surveys were conducted to assess brassica pest management practices at large scale farms (≈2.0-10.0 ha) and smallholder farms (<2.0 ha). Insecticides used on large scale farms include λ-cyhalothrin, fenvalerate, dimethoate, malathion, diazinon, dichlorvos, kelthane and lufenuron. Smallholder farmers predominantly used dimethoate, malathion, diazinon, methamidophos, dichlorvos, fenvalerate, carbaryl and methomyl. Six out of seven smallholder farmer clusters were ranked into an Intermediate Category between Integrated Pest Management (IPM) practices and Conventional Insecticide use. Smallholder farmers in the Chinamhora area were ranked into a Conventional Insecticide use category. Five out of seven large scale farms were ranked into a Conventional Insecticide use category while two of the seven farms were ranked into an Intermediate Category.

Diamondback moth larval incidence was high in the hot-dry season in October and November of both 2007 and 2008 and reached a density of 15.58 larvae per plant at Nyanga in November 2008. The major larval endoparasitoid was *Cotesia plutellae* (Hymenoptera: Braconidae) and parasitism reached 95.51% at a host density of 2.83 larvae per plant at Harem in early summer (October and November) of 2008. The larval-pupal endoparasitoid *Diadegma mollipla* (Hymenoptera: Ichneumonidae) was recorded at three high altitude sites (>1,400 m) with parasitism levels of 5.56% at ART, 4.65% at Nyanga and 5.26% at Eden. The larval endoparasitoid *Apanteles* sp. (Hymenoptera: Braconidae) reached a parasitism level of 0.93% at Eden. The pupal parasitoid *Oomyzus*

sokolowskii (Hymenoptera: Eulophidae) reached parasitism levels of 1.31% at Africa University and 2.41% at Hartzell.

Field edge effects on DBM density were tested at four large scale farms. There were significantly higher ($p<0.05$) DBM larval and pupal populations in the field interior compared to the 5 field edge rows at two farms. The other two farms had significantly higher ($p<0.05$) DBM larval and pupal populations in the 5 field edge rows compared to the field interior. Studies on unsprayed plots of covo (*Brassica oleracea* var. *acephala*), rape (*Brassica napus*), cabbage (*Brassica oleracea* var. *capitata*), Ethiopian mustard (*Brassica carinata*) and Indian mustard (*Brassica juncea*) showed that DBM and aphids (*Brevicoryne brassicae*) infested cabbage and rape. Flea beetles (*Phyllotreta* sp.) infested Indian mustard only. There was no significant difference ($p>0.05$) in DBM larval density between cabbage only and cabbage intercropped with Indian mustard.

The entomopathogen *Zoophthora radicans* caused 98.68% mortality on small (1^{st}-2^{nd} instar) DBM larvae *in vitro* and 21.34% mortality on large (3^{rd}-4^{th} instar) DBM larvae six days after treatment. *Zoophthora radicans* was not effective against larvae of *Helicoverpa armigera* and cabbage looper (*Trichoplusia ni*). There was no significant difference ($p>0.05$) in adult *C. plutellae* emergence from cocoons treated with *Z. radicans* and cocoons sprayed with water. There was 95% emergence of *C. plutellae* adults from cocoons treated with Dimethoate 40 EC. No adults of *C. plutellae* emerged from cocoons treated with Carbaryl 75 WP, Malathion 25 WP and Malathion 50 EC.

DEDICATION

This dissertation is dedicated to my wife Tsitsi, son Tanaka, daughter Tanatswa and relatives and friends who helped me in one way or another in my studies.

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CHAPTER ONE

INTRODUCTION

The diamondback moth (DBM), *Plutella xylostella* (L.) (Lepidoptera: Plutellidae), is ranked as the most destructive pest of brassicas throughout the world (Talekar and Shelton, 1993; Sarfraz *et al*., 2005). In Zimbabwe, large scale and smallholder farmers grow brassicas as one of their principal crops and DBM is a major pest of cabbage (*Brassica oleracea* var. *capitata*), covo (*Brassica oleracea* var. *acephala*) and rape (*Brassica napus*) (Jackson, 1997; Sibanda *et al*., 2000).

The production and marketing of horticultural crops in Zimbabwe provides livelihoods for large scale and smallholder farmers in all parts of the country and there is potential for substantial improvement in income and nutritional status through increased production of vegetables and fruits (CIIFAD, 1994; Jackson, 1997; Dobson *et al*., 2002). In Zimbabwe, a unilateral pest control approach that relies predominantly on the indiscriminate use of pesticides in vegetable production has been the practice (Sibanda *et al*., 2000). For the farmers, the cultivation of brassicas is not possible without extensive use of pesticides and this practice has also been observed in Southeast Asia and Pacific regions (Haseeb and Amano, 2002).

Numerous studies (Liu *et al*., 1981; Shelton *et al*., 1993; Hill and Foster, 2000 and Liu *et al*., 2000 among others) have shown that the use of insecticides is not a sustainable pest management option for farmers as it is fraught with problems such as improper handling of pesticides, increased cost of pesticides, reduced control efficacy and contamination of the farming environment (Dobson *et al*., 2002). In many developing countries, there are problems associated with the lack of appropriate and well maintained

spraying equipment. In many rural situations, the spraying equipment used by farmers does not meet specified Food and Agriculture Organization quality guidelines and minimum standards of operation (FAO, 1998). There is therefore a need for field-oriented information on insect pests of horticultural crops that can be used by farmers and extension agents.

A possible alternative to pesticides in the development of an integrated management strategy against DBM is conservation biological control using endemic parasitoids (Sarfraz *et al*., 2005). On the African continent, extensive studies on the incidence and efficacy of DBM parasitoids have been conducted in South Africa and Kenya (Kfir, 1998; Akol *et al*., 2002; Kfir, 2003b; Löhr *et al*., 2007). Effective parasitoids of DBM in South Africa and Kenya include *Cotesia plutellae* (Kurdjumov) (Hymenoptera: Braconidae), *Diadegma mollipla* (Holmgren) (Hymenoptera: Ichneumonidae) and the introduced *Diadegma semiclausum* (Hellen) (Hymenoptera: Ichneumonidae) (Kfir, 1998; Kfir, 2003b; Akol *et al*., 2002; Macharia *et al*., 2005; Löhr *et al*., 2007). Ayalew and Ogol (2006) documented the predominance of *Oomyzus sokolowskii* (Kurdjumov) (Hymenoptera: Eulophidae) in the Rift Valley region of Ethiopia where insecticide use is intensive.

In Zimbabwe, however, no work has been conducted on quantifying the incidence of DBM and its endemic parasitoids. There is little knowledge on the complex of natural enemies of DBM in Zimbabwe and these deficiencies were identified as some of the knowledge gaps that exist in a study conducted from 1997 to 2000 (Sibanda *et al*., 2000).

In light of DBM's long history of development of resistance to synthetic insecticides, a viable integration of tactics is essential to the long-term availability of

control options for DBM. Farmers typically choose the simplest, easiest and least expensive approaches to pest management that provide good economic returns. Although a system that involves both crop diversification and resistant plant varieties, or other strategies concurrently may not be well accepted by farmers (especially the large scale farmers), such solutions to pest problems must be investigated.

The optimization and integration of pest management procedures is one of the major factors in promoting sustainable agricultural systems, especially those tailored to the needs of resource poor farmers. This study was designed to generate information that would be beneficial to the production and pest management needs of brassica growers in Zimbabwe. Due to the importance of natural enemies and the key role that they play in keeping insect populations in check, it is important to know how the various cultural and pest management practices that farmers commonly use affect DBM populations in the field.

It is important to conserve natural enemies, particularly once it is determined which ones are the most important in regulating pest populations. It is also important to investigate the compatibility of integrated approaches such as the combined use of endoparasitoids and entomopathogens in the management of DBM. Overall, the study constituted a diagnostic survey of farmers' problems and priorities in the management of DBM. The study was also conducted to assess DBM incidence in different agricultural regions of Zimbabwe and to evaluate materials and techniques offering potential in DBM management.

General Objective

The overarching objective of the study was to better understand the seasonal dynamics of brassica insect pests and their natural enemies in both small scale and large scale farms in two ecological zones in Zimbabwe, with emphasis on DBM. A secondary objective was to understand differences in brassica susceptibility to DBM infestation and to generate information that can be used by farmers and crop protection practitioners in selecting tolerant brassica varieties.

Specific Objectives

Objective 1

To determine the seasonal occurrence of diamondback moth and its parasitoids in the highveld (>1,200 m) and middleveld (600-1,200 m) ecological zones of Zimbabwe.

Rationale

An understanding of the seasonal occurrence of any pest species provides farmers and crop protection practitioners with information that is relevant for the control of the particular pest. In Zimbabwe, no work has been conducted to document the seasonal occurrence of DBM and other brassica insect pests. Determining the endemic parasitoid complex that attacks DBM and other brassica insect pests provides some insight into possible pest management practices that can be implemented in brassica production systems without relying extensively on the use of synthetic insecticides.

Objective 2

To determine the relative susceptibility of brassica varieties to DBM infestation and to evaluate the impact of Indian mustard (*Brassica juncea*) as a trap crop in DBM management.

Rationale

Brassicas are one of the most diverse leafy green vegetables grown by farmers worldwide. This diversity probably also provides different levels of susceptibility to various insect pests including DBM. An understanding of the susceptibility of different brassicas to DBM attack provides growers and crop protection practitioners with knowledge on variety selection to minimize losses incurred due to DBM infestation.

Objective 3

To determine the efficacy of the entomopathogen *Zoopthora radicans* (Brefeld) Batko and synthetic insecticides against lepidopteran larvae *in vitro*. A secondary objective was to evaluate the impact of *Zoopthora radicans* and synthetic insecticides on the emergence of *Cotesia plutellae* adults from cocoons, *Diaeretiella rapae* adults from aphid mummies and DBM adults from pupae.

Rationale

The pupal (cocoon) stage of *Cotesia plutellae* and the mummy stage of *Diaretiella rapae* are considered the most resilient stages of the two parasitoids. Several studies have noted adverse effects of synthetic insecticides on larval and adult stages of parasitoids but there are limited studies of pesticide effects on pupal stages. Knowledge on the impact of pesticides on pupal stages is important in determining how these stages can withstand adverse conditions and thus help in parasitoid conservation.

CHAPTER TWO

LITERATURE REVIEW

Economic Importance of Brassica Production in Zimbabwe

Brassicas are the most widespread and one of the two most important vegetable crops grown by smallholder farmers in Zimbabwe. Brassica production, particularly rape, covo and cabbage is rivaled in terms of cultivated area and economic value only by tomato (CIIFAD, 1994; Jackson, 1997). The most widespread brassica grown in smallholder farms and in urban area backyards is covo (derived from Portuguese couve) *Brassica oleracea* var. *acephala*. This brassica variety is planted using vegetative propagation and can be harvested for up to four years (Jackson, 1997).

Other brassicas grown in Zimbabwe include Brussels sprouts (*Brassica oleracea* L. convar. *oleracea* var. *gemmifera* DC), rape (*Brassica napus* L.), Indian mustard (*Brassica juncea* (L.) Czern.) and Ethiopian mustard (*Brassica carinata* Braun), (Jackson, 1997). Across Africa, other brassicas grown include the smooth leafed kales (*Brassica oleracea* var. *acephala* DC subvar. *plana* Peterm.), thousand headed kales (*Brassica oleracea* var. *acephala* DC subvar. *millecapitata* (Lev.) Thell.), marrow stem kales (*Brassica oleracea* var. *acephala* DC subvar. *medullosa* Thell.), Curly kale (*Brassica oleracea* var. *acephala* subvar. *laciniata* L.) and tree kales (*Brassica oleracea* var. *acephala* subvar. *palmifolia* DC) (Williams *et al*., 1991).

In developing countries such as Zimbabwe, the production of brassicas is important on smallholder farms with intensive use of land, labour and pesticides (Sibanda *et al*., 2000). In eastern and southern Africa, brassicas are an important and most common vegetable in the diet of local communities. Brassicas are also an important source of

income for smallholder farmers (Mguni *et al*., 1999; Sibanda *et al*., 2000; Dobson *et al*., 2002; Massomo *et al*., 2004; Akol *et al*., 2002; Macharia *et al*., 2005).

In a bid to produce fresh vegetables for residents of large cities on a daily basis, such smallholder farms are usually located on the outskirts of large cities. In the case of Zimbabwe, the bulk of leafy vegetables are produced in Chinamhora, Murewa, Mutoko and Seke that all lie within a 100 km radius of the city of Harare (Jackson, 1997; Sibanda *et al*., 2000). In Kenya, the bulk of leafy vegetable production is practiced in areas such as Nyathuna, Kariguini, Thika and Mweya, all which are also within a 100 km radius of the city of Nairobi (Akol *et al*., 2002; Macharia *et al*., 2005). In these peri-urban smallholdings, cultivation of fresh brassicas is an important source of income, and the production of 'healthy looking' damage-free vegetables for the city dwellers is an important consideration in all cultivation practices especially crop protection.

The mainstay of pest control is the frequent use of insecticides, mainly applied using backpack sprayers with few safety provisions to the applicator. In a study conducted in peri-urban smallholdings around Harare in Zimbabwe, farmers were applying as much as 600% of the recommended dosage (Sibanda *et al*., 2000). In the same study farmers were applying some of the pesticides indiscriminately regardless of whether the compounds were registered for a particular crop or not.

DBM Physiology and Ecology

Damage caused by DBM

The diamondback moth is an oligophagous feeder of plants in the family Cruciferae (van Loon *et al*., 2002), and it presents one of the greatest challenges to brassica production in many parts of the world (Hill and Foster, 2000). This pest causes

heavy losses on brassicas, especially cabbage (Talekar and Shelton, 1993) and attacks the crop from the seedling to the harvest stage. Plants tolerate varying amounts of damage depending on species, variety and maturity. DBM larval infestations are most serious when they damage the crowns or growing points of young plants resulting in severely stunted growth. DBM larvae may also bore into heads of broccoli or cauliflower, or in the flower buds, causing economic injury and contamination. The younger larvae often cause a “window pane” effect when they feed on the spongy mesophyll (Francis *et al*., 2005).

Life Stages of DBM

Female moths start laying eggs soon after mating, and the oviposition period lasts 4 days during which the female lays 11-188 eggs (Talekar and Shelton, 1993). Soon after hatching, neonate larvae start feeding on foliage. First-instar larvae mine in the spongy mesophyll tissue, whereas older larvae feed from the lower leaf surface and usually consume all tissue except the wax layer on the upper surface, thus creating a “window” in the leaf. The duration of the four larval instars depends on temperature. Faster developmental times are reported in warm climates, and the host crop also influences development rates (Francis *et al*., 2005). The fourth-instar larvae complete feeding in 10 to 14 days and construct an open-network pupal cocoon on the leaf surface. A two-day period of quiescence marks the prepupal stage. The pupal period ranges from 4 to 15 days depending on temperature. Adult moths feed on water drops or dew and are short lived. In the tropics and sub-tropics where brassicas are grown throughout the year, all life stages of DBM can be present at any time (Talekar and Shelton, 1993).

Host Range of DBM

The diamondback moth feeds mostly on members of the family Cruciferae (Talekar and Shelton, 1993). Cultivated brassicas on which DBM feeds include cabbage (*Brassica oleracea* var. *capitata*), cauliflower (*Brassica oleracea* var. *botrytis*), broccoli (*Brassica oleracea* var. *italica*), radish (*Raphanus sativus*), turnip (*Brassica rapa pekinensis*), Brussels sprouts (*Brassica oleracea* var. *gemmifera*), Chinese cabbage (*Brassica rapa* cv. gr. *pekinensis*), kohlrabi (*Brassica oleracea* var. *gongylodes*), Indian mustard (*Brassica juncea*), rapeseed (*Brassica napus*), collard (*Brassica oleracea* var. *acephala*), pak choi (*Brassica rapa* cv. gr. *pakchoi*), saishin (*Brassica rapa* cv. gr. *saishin*), watercress (*Nasturtium officinale*), and kale (*Brassica oleracea* var. *alboglabra*) (Talekar and Shelton 1993). In East Africa however, Löhr and Gathu (2002) and Roßbach *et al*. (2005) documented the adaptive feeding of diamondback moth on peas (*Pisum sativum* L.).

The diamondback moth also feeds on numerous brassica weeds in the absence of cultivated hosts. The following brassica weeds have been reported to sustain feeding and reproduction of DBM; tower mustard [*Arabis glabra* (L.) Bernh.], horseradish (*Armoracia lapathifolia* Gilib. ex Usteri), common cress (*Barbarea stricta* Andrz. ex Besser), yellow rocket (*Barbarea vulgaris* W.T. Aiton), kohlrabi (*Brassica caulorapa* L.), rutabaga [*Brassica napobrassica* (L.) Mill.], Turkish rocket (*Bunias orientalis* L.), shepherd's purse [*Capsella bursa- pastoris* (L.) Medik.], large bittercress (*Cardamine amara* L.), heartleaf bittercress (*Cardamine cordifolia* A. Gray), cuckoo flower (*Cardamine pratensis* L.), hare's ear mustard [*Conringia orientalis* (L.) Dumort.], herb Sophia [*Descurainia sophia* (L.) Webb ex Prantl.], common wallflower [*Erysimum cheiri*

(L.) Crantz], demes rocket (*Hesperis matronalis* L.), annual candytuft (*Iberis amara* L.), Dyer's woad (*Isatis tinctoria* L.), clasping pepperweed (*Lepidium perfoliatum* L.), Virginia pepperweed (*Lepidium virginicum* L.), sweet alyssum [*Lobularia maritima* (L.) Desv.], tenweeks stock [*Matthiola incana* (L.) R. Br.], tall tumblemustard (*Norta altissima* L. Britton), kerguelen cabbage (*Pringlea antiscorbutica* R. Br.), wild radish (*Raphanus raphanistrum* L.), great yellowcress [*Rorippa amphibia* (L.) Bess.], northern marsh yellowcress [*Rorippa islandica* (Oeder) Barbás], white mustard (*Sinapis alba* L.), Charlock mustard (*Sinapis arvensis* L.), jeweled rocket (*Sisymbrium austriacum* Jacq.), hedgemustard [*Sysymbrium officinale* (L.) Scop.] and field pennycress (*Thlaspi arvense* L.) (Talekar and Shelton 1993). Alternate weed hosts are especially important in maintaining DBM populations in temperate regions in spring before cultivated crucifers are planted (Talekar and Shelton, 1993).

DBM Control Measures

Chemical Control of DBM

Sprays of *Bacillus thuringiensis* and spinosad (Entrust®) are organically acceptable management tools (Diaz-Gomez *et al*., 2000). Widely used insecticides include diazinon, emamectin benzoate, indoxacarb, spinosad, tebufenozide, endosulfan and methomyl. *Bacillus thuringiensis* products include Dipel®, Javelin® and Agree®. A new strain of *Bacillus aizawai* (Serotype H7) marketed as Xentari® has increased activity against *Plutella xylostella* (Parker *et al*., 1995). The use of insect growth regulator insecticides is becoming increasingly important in vegetable production. Lufenuron is a larvicide that inhibits chitin biosynthesis, thus interfering with the formation of the cuticle. It is a non-systemic insect growth regulator with strong stomach and moderate

contact activity. It is effective against pests resistant to organophosphates, carbamates and pyrethroids. Lufenuron is highly active against leaf feeding lepidopteran larvae and also has some ovicidal activity (Syngenta, 2004).

Problems With Chemical Control of DBM

Farmers routinely apply insecticides to control insects attacking brassicas, but the use of broad spectrum insecticides may result in pest resurgence, secondary pest upsets, and widespread pesticide resistance, and may prove detrimental to biological control agents (Hooks and Johnson, 2003). The main reason for DBM's status as a major pest is its ability to rapidly develop resistance to virtually all insecticides used to control it, leaving few available insecticides for effective control (Tabashnik *et al*., 1990; Hill and Foster, 2000; Sayyed *et al*., 2005). Resistance to carbamates and organophosphates was documented first, principally in tropical regions followed by resistance to pyrethroids, organochlorines and insect growth regulators (McHugh and Foster, 1995).

Plutella xylostella has developed resistance to pyrethroids in Southeast Asia and elsewhere (Liu *et al*., 1981; Georghiou, 1986; Sayyed *et al*., 2005). In the southeastern states of the USA, around the 1980s, pyrethroids such as permethrin, organophosphates such as methamidophos, carbamates such as methomyl and the HD1 strain of *Bt* (marketed as Dipel®) were highly effective against DMB larvae (Workman *et al*., 1980). However due to the development of resistance, these active ingredients are no longer as effective (Xu *et al*., 2001; Sayyed and Wright, 2004; Sayyed *et al*., 2005).

In addition, DBM has the distinction of being the first insect to develop field resistance to *Bacillus thuringiensis* (Tabashnik *et al*., 1990). An autosomal recessive gene in DBM was shown to confer high levels of resistance to four *Bt* toxins: Cry 1Aa, Cry

1Ab, Cry 1Ac and Cry 1F (Tabashnik *et al*., 1997). Zhao *et al*. (2001) showed that a *P. xylostella* strain resistant to the Cry 1C protoxin and transgenic broccoli expressing a Cry 1C toxin of *Bacillus thruringiensis* was also cross resistant to Cry 1Aa, Cry 1Ab, Cry 1Ac, Cry 1F and Cry 1J toxins. Zhao *et al*. (2002) also noted that DBM populations from Thailand and Hawaii showed high levels of tolerance to the naturalyte insecticide spinosad.

Insecticide resistance develops primarily as a result of selection pressure (McHugh and Foster, 1995). Control strategies that minimize DBM exposure to pesticides may be useful in managing resistance by reducing the intensity of selection. McHugh and Foster (1995) noted that overhead irrigation can reduce DBM populations. In many African situations including Zimbabwe, farmers predominantly use surface irrigation (Sibanda *et al*., 2000). In cases where farmers use overhead irrigation on brassicas, they face disease problems such as bacterial black rot disease caused by *Xanthomonas campestris* pv. *campestris* (Mguni *et al*., 1999; Massomo *et al*., 2004).

Biological Control of DBM

Natural control agents, especially parasitoids, can play an important role in *P. xylostella* management and work has been done in several countries to integrate biological and chemical control of DBM (Talekar and Shelton, 1993). All stages of diamondback moth are attacked by numerous parasitoids and predators, with parasitoids being the most widely studied (Talekar and Shelton, 1993). Larval parasitoids of DBM are the most predominant and many of the effective larval parasitoids belong to three major genera, *Diadegma*, *Cotesia* and *Apanteles* (Kfir, 2003b; Sarfraz *et al*., 2005).

The ichneumonid *Diadegma semiclausum* (Hellen) was introduced into many areas of Southeast Asia and it is playing a major role in suppressing DBM populations on brassicas (Shepard *et al*., 1999). *Cotesia plutellae* (Kurdjumov) (Hymenoptera: Braconidae) is also a potent solitary endoparasitoid of DBM larvae in Southeast Asia and the Pacific (Bach and Tabashnik, 1990; Wharton, 1993; Sarfraz *et al*., 2005). Parker *et al*. (1995) contend that in the lowland areas of the tropics and sub-tropics where temperatures are high, *C. plutellae* is the only larval parasitoid that can thrive. *Diadromus collaris* (Gravenhorst) attacks DBM pupae. It originated in Europe and was brought into Asia via Australia (Sarfraz *et al*., 2005). It complements the action of the larval parasitoid, *D. semiclausum*, to keep DBM populations below damaging levels, especially when there is reduced use of insecticides (Shepard *et al*., 1999).

Wang *et al*. (2004) observed that *Diadegma semiclausum* was highly effective in controlling DBM in seasons or regions with a mild temperature. Akol *et al*. (2002) also noted that *D. mollipla* was effective against DBM in the highland regions of East Africa in Kenya. *Diadegma insulare* (Cresson) (Hymenoptera: Ichneumonidae) is one of the most important parasitoids of *P. xylostella* in North America, and parasitism of *P. xylostella* by *D. insulare* may reach 80% (Idris and Grafius, 1993).

Since parasitoids play such an important role in checking DBM population growth, the conservation of parasitoids is basic to any sustainable IPM program (Verkerk, 2001). In the tropics and sub-tropics, community-wide management will most likely rely primarily on the conservation of as many parasitoid species as possible and the use of cultural practices (Talekar and Shelton, 1993).

Adverse Effects of Pesticides on *Cotesia* sp. and *Diadegma* sp. Parasitoids

Parasitoids are particularly susceptible to chemical insecticides, and understanding their role in the ecosystem is important for implementing integrated pest management (Shepard *et al*., 1999). In Zimbabwe no studies have been conducted to document the adverse impact of pesticides on beneficials even though evidence from other areas has shown that beneficial insects are greatly affected (Dobson *et al*., 2000).

In vegetable production and other cropping practices, beneficial species and pesticides can be effectively integrated with an adequate knowledge of pesticides' effects on natural enemies (Greathead, 1995). Hill and Foster (2000) tested the effect of various insecticides on DBM and its parasitoid *Diadegma insulare*, and they noted that only *B. thuringiensis* and tebufenozide were not toxic to *D. insulare* 24 hr after treatment. Carbaryl, permethrin and spinosad were toxic to *D. insulare*. However, because of its high susceptibility to many insecticides, including fenvalerate, permethrin, cypermethrin, azinphos-methyl and methomyl, *D. insulare* could be severely reduced in brassica fields that are sprayed frequently (Idris and Grafius, 1993; Xu *et al*., 2001).

Biological Control Using Entomopathogenic Fungi

Kfir (2003b) noted that the entomopathogen *Zoophthora radicans* can cause dramatic epizootics that decimate DBM populations particularly after periods of prolonged soft rain. The potential of various entomopathogens as biological control agents has been tested for DBM management, but few studies have demonstrated practical significance (Shah and Pell, 2003; Sarfraz *et al*., 2005). The family Entomophthorales in the fungal class Zygomycetes contains the largest number of entomopathogens (Tanada and Kaya, 1993; Shepard *et al*., 1999). The most important

genera are *Massospora*, *Neozygites*, *Conidiobolus*, *Zoophthora* (syn. *Erynia*) and *Entomophthora* (Shah and Pell, 2003). *Zoophthora radicans* infects a wide range of hosts including diamondback moth and it is probably a species complex (Verkerk, 2001; Shah and Pell, 2003; Sarfraz *et al*., 2005).

In most cases, *Z. radicans* infection results from the passage of infectious hyphae through the integument. In some cases, the digestive tract, mouthparts or the anal orifice, the genital tract and tracheae are also sites of penetration (Tanada and Kaya; 1993; Shah and Pell, 2003). When the cuticular barrier has been crossed, the fungus reaches the body cavity and develops from foci under the epidermis (Tanada and Kaya, 1993). The haemocoel is most often invaded by blastospores and the host responds through haemocytic reaction or phagocytosis, but chiefly by cellular or non-cellular encystment of invading hyphae and blastospores, resulting in the formation of granuloma (Tanada and Kaya, 1993). Generally death occurs before the proliferation of blastospores and fungus then develops like a saprophyte in the haemocoel of the cadaver, which it completely invades (Shah and Pell, 2003).

Trap Cropping

Partly because of a desire to reduce reliance on off-farm inputs (sustainable agriculture) and to provide a more ecological approach to insect pest management, cultural pest control measures such as vegetation diversification are being investigated (Hooks and Johnson, 2003). Several studies have demonstrated the value of *Brassica juncea* as a trap crop for DBM in brassica production (Parker *et al*., 1995; Charleston and Kfir, 2000; Cao *et al*., 2005). Åsman (2002) demonstrated that DBM preferred Indian mustard (*Brassica juncea*) over white cabbage (*Brassica oleracea* var. *alba*). Hooks and

Johnson (2003) noted the value of *Brassica juncea* and collards for DBM attraction and colonization when intercropped with cabbage and they also noted that tomato (*Lycopersicon esculentum*), sage (*Salvia officinalis*), white clover (*Trifolium repens*), thyme (*Thymus vulgaris*) and red clover (*Trifolium pratense*) are preferred for DBM oviposition.

Åsman *et al*. (2001) noted that *P. xylostella* laid fewer eggs on white cabbage intercropped with tall red clover (*Trifolium pratense* L.), compared with monoculture cabbage. Hooks and Johnson (2003) noted that parasitism of *P. xylostella* by *Diadegma insulare* was higher in broccoli adjacent to nectar-producing plants than in broccoli surrounded by bare ground. Several workers (Gourdine *et al*., 2003; Hooks and Johnson 2003 among others) noted that wild flowers increased the longevity and fecundity of *D. insulare* and concluded that seasonal manipulations of wild flower species adjacent to cabbage fields could increase their effectiveness against DBM.

Mitchell *et al*. (2000) planted collard on cabbage field peripheries and demonstrated its effectiveness as a trap crop to manage DBM. They suggested that collards should be superior to *B. juncea*, as collards can be planted at the same time as cabbage and will last the duration of the cabbage season, whereas *B. juncea* may require several plantings during the growing season. In Hawaii, Bach and Tabashnik (1990) noted that the presence of tomato next to cabbage significantly increased DBM parasitism by *Cotesia plutellae*.

Host Plant Resistance

Host plant resistance research to date indicates that *Brassica* strains expressing the glossy leaf characteristic show some behavioral based resistance to DBM, and larval

mortality occurs predominantly during the first instar (Eigenbrode and Shelton, 1992; Justus *et al*., 2000; Ulmer *et al*., 2002). Several cultivated brassicas, notably cabbage (*B. oleracea* var. *capitata*), broccoli (*B. oleracea* var. *italica*) and oilseed rape (*Brassica napus*) have been transformed to express *Bt* genes (Zhao *et al*., 2002; Schuler *et al*., 2004; Cao *et al*., 2005) although so far none of these have been commercialized. The downside of *Bt* transgenic brassicas is that the DBM larvae that feed on *Bt* crops are not suitable for the development of the endoparasitoid *Cotesia plutellae* (Schuler *et al*., 2004). Commercial releases of *Bt* brassicas may not necessarily benefit farmers in developing countries because such varieties may be expensive for the farmers. Any release of *Bt* brassicas should be accompanied by a resistance management strategy to preserve susceptibility in DBM populations to avoid widespread resistance.

Prospects for Integrated Management of DBM

The key to a successful IPM program is to sample fields frequently, identify harmful pests and beneficial insects and make spraying decisions based on what is in the field rather than what the farmer thinks might be there (Vambe, 1997; Francis *et al*., 2005). Gurr *et al*. (2004) contend that IPM is basically the combined use of multiple pest control methods informed by monitoring of pest densities. However, in Zimbabwe and many other African farming situations, no brassica insect pest threshold levels have been established and this makes pest control using thresholds difficult to implement.

Conventional vegetable production systems are dominated by monoculture landscapes that do not carry the critical floral diversity that is conducive for conservation biological control. One approach that has been proposed is habitat management to create a suitable ecological infrastructure within the agricultural landscape to provide resources

such as food for adult natural enemies and alternative prey or hosts (Landis *et al*., 2000; Gurr *et al*., 2004).

Brassica IPM depends on a good understanding of local farming conditions and factors affecting DBM population dynamics. There is no universal blueprint for DBM management because brassica production systems are highly diverse. The adoption of biological control, habitat management practices and other environmentally acceptable practices will go a long way in promoting sustainable brassica pest management systems.

CHAPTER 3

SURVEY OF BRASSICA FIELDS FOR THE DIAMONDBACK MOTH AND ITS PARASITOIDS IN ZIMBABWE

Introduction

The diamondback moth (DBM), *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) is the most destructive cosmopolitan pest of brassicas (Talekar and Shelton, 1993). In Zimbabwe, a unilateral pest control approach that relies predominantly on indiscriminate use of pesticides has been the practice (Sibanda *et al*., 2000). Many farmers believe that the cultivation of brassicas is not possible without extensive use of pesticides and this scenario has also been observed in Southeast Asia and Pacific regions (Haseeb and Amano, 2002). Several studies (Liu *et al*., 1981; Shelton *et al*., 1993; Hill and Foster, 2000 and Liu *et al*., 2000 among others) have shown that the use of insecticides is not a sustainable pest management option for smallholder farmers as it is fraught with problems such as improper handling of pesticides, increased cost of pesticides, reduced control efficacy and dangers of contamination of the farming environment (Dobson *et al*., 2002).

A possible alternative to pesticides in the development of an integrated management strategy against DBM is conservation biological control. On the African continent, extensive studies on the incidence and efficacy of DBM parasitoids have been conducted in South Africa and Kenya (Kfir, 1998; Akol *et al*. 2002; Kfir, 2003b; Löhr *et al*., 2007). The diamondback moth may have its origin in Europe, but on the basis of the presence of its biocontrol agents and host plants, Kfir (1998) suggested that DBM may have originated in South Africa.

Diamondback moth population dynamics can be influenced by both agronomic and pest management practices implemented by farmers. Due to the importance of natural enemies and the key role they play in controlling insect populations, it is important to know how the various cultural and management practices that farmers commonly use affect DBM populations in the field. In Zimbabwe, however, no work has been conducted on quantifying the incidence of DBM and its endemic parasitoids. Little is known about the complex of DBM natural enemies in Zimbabwe and this knowledge gap provided the impetus to conduct surveys in areas where brassica production is concentrated.

The surveys were conducted on farms in the highveld (>1,200 m) and the middleveld (600-1,200 m) as these are the zones where brassicas are predominantly grown in both smallholder farms (less than 2 ha under brassicas) and large scale farms (between 2.0 ha and 10.0 ha under brassicas) (Jackson, 1997). The rainfall regime in the highveld ranges from 750 to 1,500 mm per annum while in the middleveld the rainfall ranges from 650 to 1,000 mm per annum. The overarching objective of the study was to develop an inventory of endemic parasitoids of DBM and to evaluate farming practices that may hinder the effectiveness of these parasitoids across a range of brassica cropping systems.

Materials and Methods

Assessment of Smallholder Farms

Field surveys were conducted in smallholder farms in Chinamhora, Honde Valley, Watsomba, Matema, Mhakwe, and around Africa University campus from August to

November in 2007 and August to November in 2008. Data were collected on several aspects of pest management and crop production practices.

Assessment of Large Scale Farms and Research Stations

Field surveys were conducted at large scale farms namely; ART, Delta, Odzi, Matongo, Africa University, Weirmouth, Eden, Harem and Dombera from August to November in 2007 and August to December in 2008 and January 2009 to March 2009. Research stations assessed were the Horticulture Research Centre and Nyanga Experiment station. The sites for the field surveys are indicated on the map in Appendix A and the GPS co-ordinates for the sites are given in Table 3.1.

Classification of Pest Management Practices on Farms

Detailed information on pest management practices such as crop scouting procedures and the frequency and types of insecticide applications were obtained from interviews with the farmers. Five spraying events were monitored at large scale farms and aspects monitored included volume application rates, dosages and nozzle types. Spray distribution pattern monitoring was done using Ciba-Geigy® water sensitive paper. A pest management index (MI) was derived for each farm using an adaptation of the method proposed by Furlong *et al*. (2004) (Table 3.2). Farm management practices consistent with the adoption and application of IPM were awarded a positive score, while practices in direct opposition to principles of IPM were awarded a negative score. Practices that were neither consistent with, nor opposed to IPM were awarded a score of zero. Scores were weighted to reflect the importance of a given practice within the system and scores for each practice were summed to generate the management index (MI) for each farm. An

index above 5.2 is consistent with an IPM approach and an index between 0 and 5.2 is intermediate, while an index of less than 0 indicates reliance primarily on insecticides.

Field Records

A standard scouting form was used to record counts on small DBM larvae (1^{st} -2^{nd} instars), large DBM larvae (3^{rd}-4^{th} instars), DBM pupae and parasitized DBM larvae or pupae (noted as parasitoid cocoons). Other pests recorded were cabbage moth larvae (*Crocidolomia* sp.), aphid nymphs (*Brevicoryne brassicae*) and parasitized aphids, cabbage looper larvae (*Trichoplusia ni*), *Helicoverpa armigera* larvae, webworm larvae (*Hellula undalis*), sawfly larvae (*Athalia* sp.) and flea beetle adults (*Phyllotreta* sp.). A reading of the Geographical Positioning System (GPS) co-ordinates was taken using a Garmin® Channel 12 GPS reader at the center of each field

Scouting Procedure in Brassica Fields

In each field, a total of 75 plants were scouted. These were made up of three replicates of 25 plants. For each replicate, five whole plants at five randomly selected stations in a zig-zag path were scouted as recommended by Smith and Shepard (2004).

Edge Effects on DBM Larval and Parasitoid Populations

Assessments of edge effects on DBM larval and parasitoid population densities on cabbage were conducted at four large scale farms, namely ART, Eden, Harem and Weirmouth from October to November in 2008. At each farm, records of small DBM larvae, large DBM larvae, DBM pupae and *Cotesia plutellae* cocoons were taken separately for three replicates of 25 plants in the field interior and three replicates of 25 plants at the 5 field edge rows. In this study, grasses planted for soil erosion control were the predominant type of vegetation on the field edges.

Laboratory Evaluation of Larval and Pupal Parasitism

Larvae and pupae of DBM and other pests were collected from the field and reared in the laboratory to determine parasitism levels in the field. Each DBM larva was placed in a Perspex® plastic diet cup containing fresh covo leaf discs. Rearing was done in a constant environment room at $24^0C \pm 2^0C$ and 16:8 hours light: dark. Percentage DBM parasitism was calculated separately for small DBM larvae and large DBM larvae using the formula proposed by McCutcheon (1987) as follows:

% parasitism= [Number of larvae from which a parasitoid emerged]/
[total number of larvae collected - (diseased larvae+
larvae that died of undetermined causes)] X 100.

Parasitoid Identification

Parasitoid specimens were fixed in 70% ethanol in glass vials. Parasitoid identification was based predominantly on wing morphology, using taxonomic keys in three texts, namely Scholtz and Holm (1985), Arnett (1997) and Azidah *et al*. (2000). A stereo-microscope was used to view wing morphology at a magnification of X4.0. For tiny specimens, wings were dissected and mounted on slides and viewed under a compound microscope at a magnification of X40. A microscope mounted camera (Motic Images Plus 2.0 ML®) was used to magnify images from the compound microscope. Voucher specimens of pest species and parasitoids were deposited in the Clemson University Arthropod Collection (CUAC).

Data Analysis

Minitab® Statistical Package Version 15 (Minitab, 2006) was used to generate means of DBM counts and percentage parasitism for the survey sites. For the assessment of field edge effects on DBM populations, a t-test between two independent samples

(α=0.05) was used to compare means of small DBM larvae, large DBM larvae, DBM pupae and *Cotesia plutellae* cocoons in the field interior and the 5 field edge rows at four large scale farms.

Table 3.1. Sites for Surveys and Field Trials Conducted in Zimbabwe from July 2007 to April 2009.

Ecological zone	District	Site [1]	GPS Co-ordinates	Altitude (m)
Highveld	Harare			
(>1,200 m)		ART	$17^0$42’54.3’’S: $31^0$03’43.3’’E	1,523
		Chinamhora*	$17^0$32’25.2’’S: $31^0$10’49.8’’E	1,497
	Marondera			
		HRC	$18^0$10’32.4’’S: $31^0$27’80.2’’E	1,628
		Delta	$18^0$11’33.4’’S: $31^0$51’93.2’’E	1,474
	Chimanimani			
		Dombera	$19^0$49’07.3’’S: $32^0$54’49.8’’E	1,372
	Nyanga			
		NES	$18^0$17’17.3’’S: $32^0$44’69.9’’E	1,851
		Matema*	$18^0$03’91.1’’S: $32^0$51’81.1’’E	1,631
	Mutasa			
		Watsomba*	$18^0$39’51.8’’S: $32^0$37’57.4’’E	1,408
		Honde Valley*	$18^0$34’28.0’’S: $32^0$42’69.0’’E	1,394
	Mutare			
		Eden	$19^0$06’22.4’’S: $32^0$44’47.7’’E	1,402
		Harem	$19^0$08’69.6’’S: $32^0$43’36.5’’E	1,465
Middleveld				
(600-1,200 m)	Chimanimani			
		Mhakwe*	$19^0$48’03.9’’S: $32^0$38’50.5’’E	990
	Mutasa			
		AU	$18^0$53’70.3’’S: $32^0$36’27.9’’E	1,131
		Hartzell	$18^0$53’43.0’’S: $32^0$35’23.7’’E	1,096
		Odzi	$18^0$52’60.7’’S: $32^0$30’17.7’’E	1,078
		Matongo	$18^0$55’20.9’’S: $32^0$30’44.1’’E	1,029
	Mutare			
		Weirmouth	$18^0$59’19.9’’S: $32^0$34’92.2’’E	1,028

[1] = ART= Agricultural Research Trust farm
HRC= Horticulture Research Centre
NES= Nyanga Experiment Station
AU= Africa University farm

* = Smallholder farming areas

Table 3.2. Scoring Scale on Insect Pest Management Practices Used to Derive Management Indices (MI) at Farms in Zimbabwe.[1]

Pest management practice	Answer	Score
Production break	Yes	+ 1
	No	- 1
Conservation of natural enemies	Yes	+ 1
	No	0
Regular crop scouting	Yes	+ 2
	No	0
Threshold based decision making	None (calendar sprays)	- 2
	Presence/absence of pest	0
	High/low pest numbers	+ 1
	Pest pop counts	+ 2
	Pest counts +parasitism rates	+ 3
Use of organophosphates or pyrethroids	≥ 2 applications per crop	- 2
	1 application per crop	- 1
	None	+ 1
No. of insecticide applications per crop	0-3	+ 1
	4-6	0
	7-9	- 1
	10-14	- 2
	≥ 15	- 3
Tank mixes of insecticides	Yes	- 1
	No	0

[1] = The scale was adapted from Furlong *et al*. (2004).

Results

Smallholder Farms

The major brassica types grown in smallholder farms were covo, rape and cabbage. Smallholder farmers predominantly used organophosphate insecticides such as dimethoate, malathion and diazinon and the carbamate, methomyl to control brassica pests (Table 3.3). Although diazinon is not registered for DBM control on brassicas, it was used extensively. Farmers in the Chinamhora smallholder farming area also used the organophosphates methamidophos and dichlorvos, the carbamate carbaryl and the

pyrethroid fenvalerate in addition to the insecticides used by other smallholder farmers (Table 3.3). The insecticides dimethoate, fenvalerate, λ-cyhalothrin, methomyl and carbaryl are also not registered for DBM control on brassicas. Data on pesticide management indices showed that smallholder farms fell into the Intermediate Category between IPM practices and Conventional Insecticide use with management indices between 0 and 5.2 (Figure 3.1). In Chinamhora where insecticide use is intensive, a negative management index of -1.0 was obtained (Figure 3.1) placing the Chinamhora farmers' cluster into a Conventional Insecticide use category that is inconsistent with IPM practices.

Large Scale Farms

Large scale farmers used organophosphates such as dimethoate, malathion, diazinon and dichlorvos, organochlorines such as kelthane, pyrethroids such as λ-cyhalothin and fenvalerate and the insect growth regulator lufenuron (Match® 50 EC) (Table 3.3). ART farm and Delta farm fell into the Intermediate Category with scores of +3 and +2 respectively (Figure 3.2). The rest of the large scale farms fell into a Conventional Insecticide use category with scores below 0 (Figure 3.2).

Table 3.3. Insecticides Used to Control Insect Pests of Rape, Covo and Cabbage on Farms in Zimbabwe.

Farm category	Insect pest	Pesticides used	Periods of high pest incidence
Smallholder farms	Aphid	dimethoate, malathion diazinon	August- November
	DBM	diazinon*, methomyl*	September-November
	Bollworm	malathion	December- February
Chinamhora farms	Aphid	dimethoate	August-November
	DBM	diazinon*, carbaryl*, dimethoate*, fenvalerate*, malathion, dichlorvos methamidophos	October-December
	Cabbage looper	carbaryl	December-February
	Webworm	diazinon* methamidophos	September-December
Large scale farms	Cutworm	λ-cyhalothrin	Throughout the year
	Aphid	dimethoate, diazinon, dichlorvos	August- October
	DBM	lufenuron, λ-cyhalothrin* fenvalerate*, malathion	September-November
	Webworm	kelthane*	September-December

* = Indicates a pesticide that is not registered for use against the particular pest.

DBM Larval Density

DBM larval density for the period October to December 2008 ranged from 0.19 larvae per plant at Delta to 15.58 larvae per plant at Nyanga Experiment station (Table 3.4). Half of the large scale farms had DBM larval densities of less than 1 larva per plant.

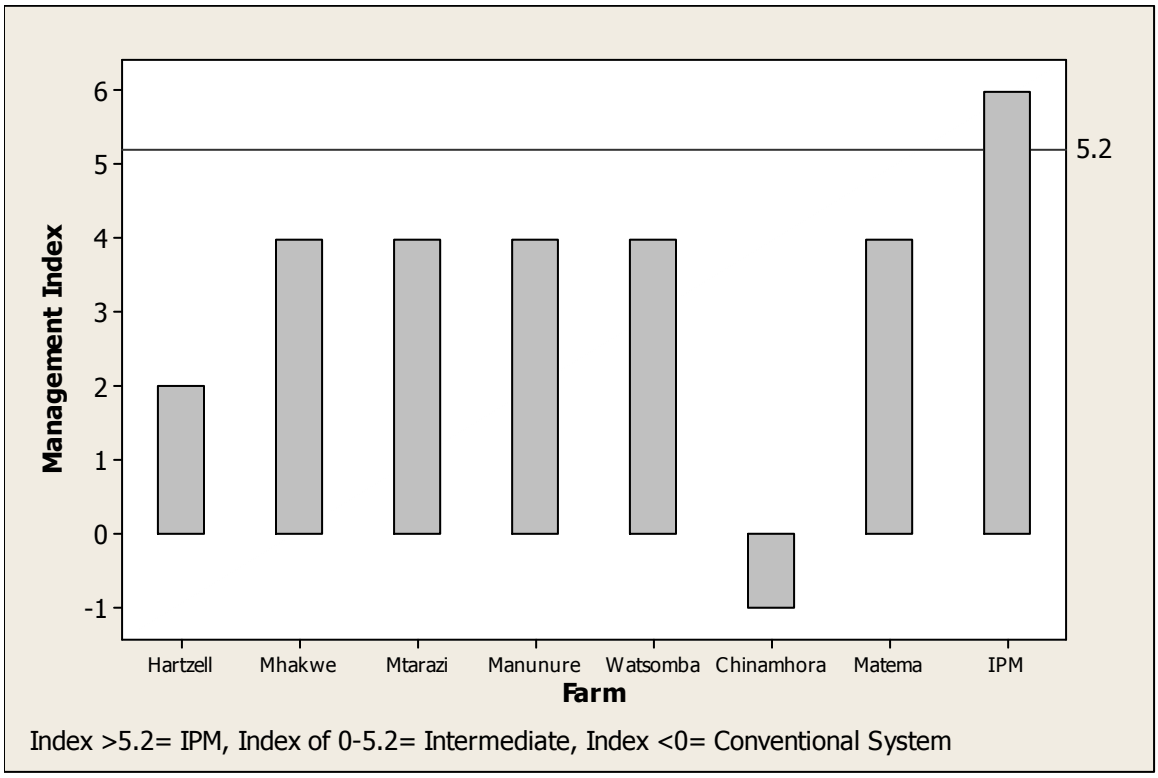

Figure 3.1: Management Indices for Smallholder Brassica Farms in Zimbabwe.

DBM Parasitism

Parasitoid specimens from DBM and other lepidopterous pests of brassicas were obtained from the field as cocoons or after rearing in the laboratory. The predominant parasitoid of DBM was the solitary larval endoparasitoid *Cotesia plutellae* and was detected on all farms in both the highveld and middleveld. Percentage parasitism by *C. plutellae* ranged from 15.51% at Eden estate to 95.51% at Harem farm (Table 3.4). The solitary larval endoparasitoid *Apanteles* sp. was recorded from DBM larvae at Eden estate only with a mean parasitism of 0.93% (Table 3.4). The solitary larval-pupal endoparasitoid *Diadegma mollipla* was recorded from DBM pupae at three highveld sites, with parasitism rates of 5.56% at ART farm, 4.65% at Nyanga and 5.26% at Eden (Table 3.4).

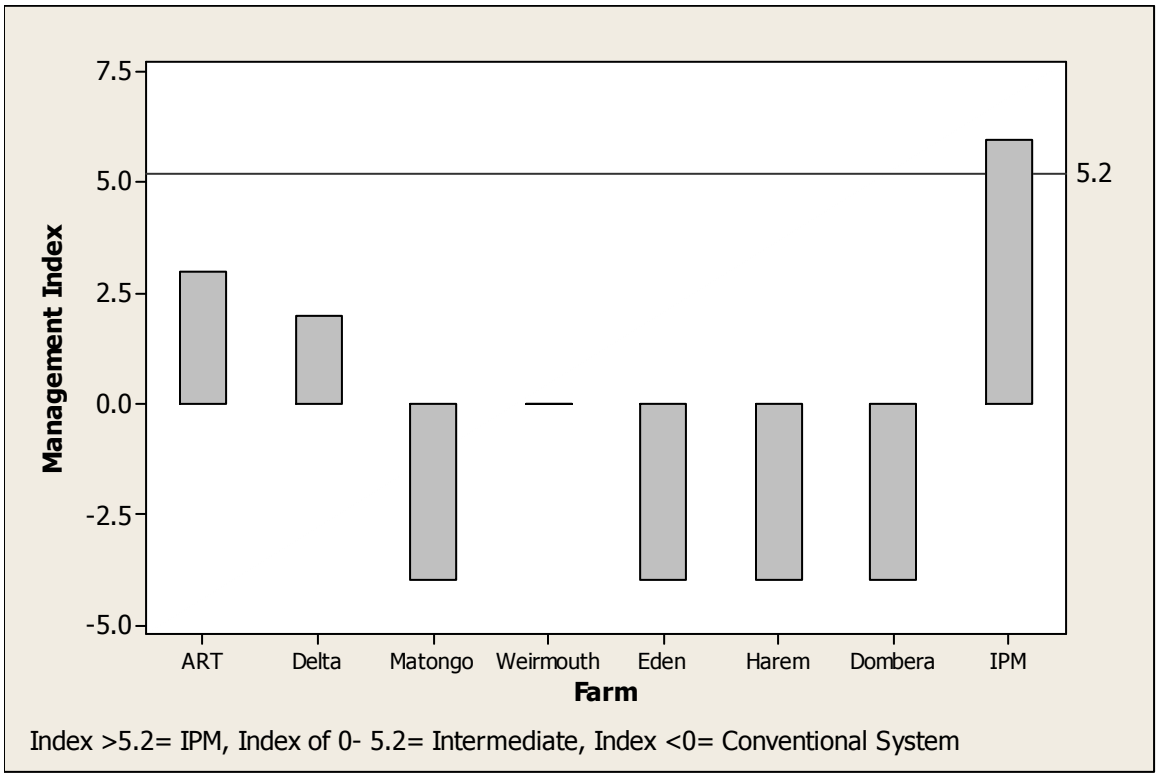

Figure 3.2: Management Indices for Large Scale Brassica Farms in Zimbabwe.

The gregarious larval-pupal endoparasitoid *Oomyzus sokolowskii* was recorded from DBM pupae at two sites in the middleveld with parasitism levels of 1.31% at Africa University and 2.41% at Hartzell (Table 3.4).

Laboratory rearing of field collected lepidopteran larvae also yielded braconid parasitoids of other brassica insect pests at Hartzell, with a parasitism rate of 49.68% for *Helicoverpa armigera* and 3.33% for cabbage moth (*Crocidolomia* sp.). At Weirmouth, 2.51% of cabbage moth larvae were parasitized by a braconid wasp and 1.59% of cabbage looper larvae were parasitized by a gregarious encyrtid wasp. At Eden estate there was 3.33% parasitism of cabbage looper by a tachinid fly (Table 3.5). The braconid wasp *Diaretetiella rapae* parasitized aphids at ART farm, AU, Hartzell, HRC, Nyanga and Weirmouth with parasitism ranging from 10.32% at Hartzell to 50.76% at ART farm

(Table 3.5). A cynipid hyperparasitoid species was recorded from aphid mummies at Hartzell, with a parasitism rate of 0.94% (Table 3.5).

Edge Effects on DBM Larval and Parasitoid Populations

At ART farm, there was a significantly higher density of large DBM in the field interior (t= 7.18, p= 0.019) compared to the 5 field edge rows. There were no significant differences in the densities of small DBM larvae, DBM pupae and *Cotesia plutellae* cocoons (Table 3.6). At Eden Estate there was a significantly higher density of DBM pupae at the 5 field edge row compared to the field interior (t= - 2.61, p= 0.048). There were no significant differences in densities of small DBM larvae, large DBM larvae and *Cotesia plutellae* cocoons (Table 3.6).

At Harem farm there was a significantly higher density of small DBM larvae in the field interior compared to the 5 field edge rows (t=5.00, p= 0.038) but there was significantly higher density of large DBM larvae at 5 field the edge rows compared to the field interior (t= -5.76, p=0.029) and a higher density of *Cotesia plutellae* cocoons at the 5 field edge rows compared to the field interior (t= -12.9, p=0.006). There was no significant difference in the density of DBM pupae (Table 3.6).

At Weirmouth there was a significantly higher density of small DBM larvae at the 5 field edge rows compared to the field interior (t= -6.33, p=0.024) and a significantly higher density of large DBM larvae at the 5 field edge rows compared to the field interior (t=- 45.3, p= 0.000) (Table 3.6). No DBM pupae were recorded and there was no significant difference in *Cotesia plutellae* cocoon density in the field interior compared to the 5 field edge rows (Table 3.6).

Table 3.4: DBM Parasitoids Recorded from October 2008 to December 2008 on Large Scale Farms in Zimbabwe.

Parasitoid family	Recovery location[1]	DBM larvae per plant (±SE) n=75	% DBM parasitism (±SE)	Host specimens
Braconidae				
Cotesia plutellae	ART	0.83±0.08	20.67±15.07	35
	HRC	1.07±0.09	31.03± 5.79	78
	Delta	0.19±0.03	45.04±12.33	23
	Odzi	4.55±0.98	50.00±29.39	78
	Nyanga	15.58±2.82	51.75±10.48	129
	AU	0.96±0.31	43.08±16.71	29
	Eden	0.84±0.05	15.51±12.66	108
	Harem	2.83±0.28	95.51± 3.67	146
	Weirmouth	5.49±0.31	67.33±18.77	124
	Dombera	0.36±0.06	72.33±14.68	24
Apanteles sp.	Eden	0.84±0.05	0.93± 0.08	108
Ichneumonidae				
Diadegma mollipla	ART	0.83±0.08	5.56±1.69	35
	Nyanga	15.58±2.82	4.65±0.97	129
	Eden	0.84±0.05	5.26±1.11	108
Eulophidae				
Oomyzus sokolowskii	AU	0.96±0.31	1.31±0.83	153
	Hartzell	0.38±0.09	2.41±0.96	83

[1] = ART= Agricultural Research Trust
HRC= Horticulture Research Centre
AU= Africa University

Table 3.5: Parasitoids of Insect Pests Other Than DBM Recorded in Zimbabwe from December 2008 to March 2009.

Insect Pest	Parasitoid family	Recovery site[1]	% Parasitism (±SE)	Host specimens
Helicoverpa armigera	Braconidae	Hartzell	49.68±8.45	54
Crocidolomia sp.	Braconidae	Hartzell	3.33±0.93	38
		Weirmouth	2.51±0.89	46
Trichoplusia ni	Tachinidae	Eden	3.33±1.96	24
	Encyrtidae	Weirmouth	1.59±0.74	108
Brevicoryne brassicae	Braconidae *Diaeretiella rapae*	AU	13.94±5.38	215
		ART	50.76±9.37	106
		Hartzell	10.32±2.59	127
		HRC	11.71±1.43	208
		Nyanga	14.83±7.94	221
		Weirmouth	23.27±8.11	203
	Cynipidae (hyperparasitoid)	Hartzell	0.94±0.01	213

[1] AU = Africa University
ART= Agricultural Research Trust
HRC= Horticulture Research Centre

Table 3.6: A t-test Comparison of Edge Effects on DBM Life Stages and *Cotesia plutellae* Cocoon Densities at Four Large Scale Farms in Zimbabwe from October to November 2008.

Farm	DBM stage or *Cotesia*	field interior (Mean±SE) n=75	field edge (Mean±SE) n=75	statistics[1]
ART	small	0.25±0.09	0.12±0.02	t= 1.80, p= 0.214
	large	0.57±0.06	0.32±0.02	t= 7.18, p= 0.019*
	pupae	0.63±0.05	1.41±0.18	t= -3.95, p= 0.058
	Cotesia	0.03±0.03	0.00±0.00	t= 1.00, p= 0.423
Eden	small	0.17±0.05	0.19±0.04	t= -0.40, p= 0.704
	large	0.53±0.12	0.49±0.16	t= 0.34, p= 0.747
	pupae	0.13±0.02	0.21±0.04	t= -2.61, p= 0.048*
	Cotesia	0.35±0.04	0.28±0.04	t= 1.49, p= 0.195
Harem	small	0.20±0.05	0.07±0.03	t= 5.00, p= 0.038*
	large	1.03±0.07	2.83±0.28	t= -5.76, p= 0.029*
	pupae	0.12±0.02	0.15±0.09	t= -0.40, p= 0.728
	Cotesia	1.85±0.15	9.55±0.44	t= -12.9, p= 0.006*
Weirmouth	small	1.37±0.01	2.35±0.15	t= -6.33, p= 0.024*
	large	4.12±0.29	11.4±0.15	t= -45.3, p= 0.000*
	pupae	0.00±0.00	0.00±0.00	t= - p= -
	Cotesia	0.03±0.03	0.00±0.00	t= 1.00, p= 0.423

[1] * = significant difference at α=0.05

Discussion

Smallholder farmers predominantly used organophosphate and pyrethroid insecticides for pest control on brassicas. One major reason why these insecticides are widely used is because they are relatively cheap when compared to the more benign compounds such as insect growth regulator (IGR) insecticides (Dobson *et al*., 2002). According to the Food and Agriculture Organization (1998), organophosphates such as methamidophos and dichlorvos are among the most toxic insecticides to human beings and yet these were widely used by smallholder farmers in the Chinamhora area. In addition, these insecticides are not even registered for use on vegetable crops (Syngenta,

2004). The derivation of the pesticide management indices showed that the Chinamhora area fell into the Conventional Insecticide use category. This finding corroborates earlier studies which suggested that the Chinamhora area is a high pesticide use area (Sibanda *et al*., 2000).

On large scale farms the organophosphate insecticides were widely used. Organochlorines such as kelthane were also in use and yet the use of these compounds is now highly restricted all over the world (FAO, 1998). On some farms, however, more environmentally friendly compounds such as the insect growth regulator lufenuron (Match® 50 EC) were being used. There were indications that large scale farmers are capable of switching to more selective and environmentally safe pesticides if these were readily available from the agrochemical suppliers. ART farm and Delta farm fell into the Intermediate Category as a result of their judicious use of insecticides based on pest damage rather than routine sprays.

Data on pest management indices showed that most of the smallholder farms fell into an Intermediate Category between IPM practices and Conventional Insecticide use practices. This factor is an indication that there is scope for the promotion of more sustainable pest management systems such as conservation biological control (CBC) being promoted by Gurr *et al*. (2004) among other workers. In many rural farms, crop production relies extensively on the use of locally available organic materials such as animal manures for soil fertility and agroforestry trees for livestock feed. It may be possible to introduce other floral species that can enhance the survival of parasitoid species on smallholder farms.

The objective of any pest control strategy is to reduce pest populations to non-economic levels (Francis *et al*., 2005). In Australia and the United States, farmers use a threshold level of 1 DBM larva per plant (Furlong *et al*., 2004; Khan *et al*., 2004; Smith and Shepard, 2004). In Zimbabwe however, no threshold levels for brassica pests have been established (Dobson *et al*., 2002). Thus most large scale brassica growers end up applying routine sprays to avoid insect pest damage.

Parasitoids are particularly susceptible to chemical insecticides and understanding their role in the ecosystem is important for implementing integrated pest management (Shepard *et al*., 1999). The solitary larval endoparasitoid *Cotesia plutellae* was the major parasitoid of DBM in Zimbabwe with parasitism ranging from 15.51% to 95.51% at different farms. Nofemela and Kfir (2005) reported similar rates of DBM parasitism in South Africa. The other solitary larval endoparasitoid recorded was *Apanteles* sp. [probably *Apanteles halfordi* Ullyett (Hymenoptera: Braconidae)]. Two larval-pupal endoparasitoids were recorded. *Oomyzus sokolowskii* (Kurdjumov) (Hymenoptera: Eulophidae), which is the only gregarious primary parasitoid of *P. xylostella* was the second most abundant DBM parasitoid in South Africa (Kfir, 2003b; Nofemela and Kfir, 2005). The other larval-pupal endoparasitoid recorded was *Diadegma mollipla* (Holmgren) (Hymenoptera: Ichneumonidae).

In the Lexington County of South Carolina, Khan *et al*. (2004) found *Diadegma insulare* as the major parasitoid of DBM with parasitism ranging from 0 to 58.5% while McCutcheon *et al*. (2004) noted DBM parasitism rates by *Diadegma insulare* ranging from 24.3% in Lexington County to 45.2% at the Coastal Research and Education Center in Charleston, SC. Akol *et al*. (2002) noted that *D. mollipla* provided limited control of

DBM in Kenya, while Ayalew and Ogol (2006) noted that *Diadegma* sp. was the predominant DBM parasitoid in Ethiopia. The fact that *D. mollipla* was recorded from only three high altitude sites in Zimbabwe could be an indication that the parasitoid is only active at cooler high altitude areas and this certainly applies to the Kenyan and Ethiopian highlands where *D. mollipla* was noted by Akol *et al*. (2002) and Ayalew and Ogol (2006) respectively.

Azidah *et al*. (2000) taxonomically revised the species of *Diadegma* attacking *P. xylostella* and noted that *D. mollipla* is an Afrotropical species and it is also a parasitoid of the potato tuber moth, *Phthorimaea operculella* (Zeller). Kfir (2003a) and Roßbach *et al*. (2005) suggested that DBM may not be the main host of *D. mollipla* and cabbage is not a significant source of attractants for this parasitoid. Perhaps, this observation may partly explain why parasitism rates of *D. mollipla* on cabbage in Zimbabwe were low ranging from 4.65% to 5.56%.

No egg parasitoids of DBM were recorded from this study and this could be as a result of the non-existence of endemic egg parasitoids of DBM rather than the failure to detect these at sites surveyed in Zimbabwe. Sarfraz *et al*. (2005) noted *Trichogramma pretiosum* and *Trichogrammatoidea bactrae* as the principal egg parasitoids of DBM in Southeast Asia and Australia, but in much of the literature on DBM parasitism in Southern Africa (Kfir, 1998; Kfir, 2003b among others), the egg parasitoids of DBM documented are *Chelonus curvimaculatus* Cameron (Hymenoptera: Braconidae) and *Chelonus* sp. (Hymenoptera: Braconidae).

Based on wing morphological features, the braconid parasitoid recorded parasitizing *Helicoverpa armigera* at Hartzell is most likely to be *Cotesia marginiventris*

that parasitizes heliothine species (van den Berg and Cock, 2000). *Cotesia plutellae* can also parasitize other host species besides *Plutella xylostella* in an adaptive process called conformity. In this case, *C. plutellae* can parasitize other lepidopteran species in the absence of its preferred host so as to bridge the reproductive step. A braconid parasitoid of cabbage moth was also recorded in field surveys with low levels of parasitism at Hartzell (3.33%) and Weirmouth (2.51%). There possibly is no fully established guild of effective endemic parasitoids that may keep the cabbage moth in check. Shepard *et al*. (1999) noted that in Southeast Asia, indigenous parasitoids of cabbage moth were not able to regulate populations of this pest.

The cabbage aphid parasitoid *Diaeretiella rapae* (McIntosh) was ubiquitous in all brassica fields assessed in Zimbabwe. There was no noticeable damage incurred due to aphid infestation possibly because of the impact of the parasitoid. *D. rapae* is a solitary endoparasitoid of adult and immature stages of several aphid species that infest brassicas with *Brevicoryne brassicae* being the principal host (Vaughn *et al*., 1996). Primary aphid parasitoids are found in the families Braconidae and Aphelinidae. These in turn are attacked by a species rich community of hyperparasitoids (Sullivan and Völkl, 1999). In Zimbabwe, a hyperparasitoid species (Alloxystidae; Alloxystinae) which attacks the braconid sub-family Aphidiinae was recorded at Hartzell.

The identification of parasitoid specimens in the current study was based entirely on morphological characters and this can be a problem when dealing with cryptic species. New diagnostic techniques such as the analysis of the 16 S gene region of the mitochondrial genome have been used to differentiate cryptic species of *Cotesia* (Rattan *et al*., 2006).

Assessment of edge effects on DBM larval and parasitoid population densities conducted at four large scale farms did not yield conclusive results on the impact of edges on DBM larval, pupal and parasitoid densities. Several workers have noted that the abundance and diversity of predators and parasities within a field are closely related to the nature of the vegetation in the field. Many agroecosystems are unfavorable environments for natural enemies due to high levels of disturbance (Landis *et al*., 2000). In Zimbabwe, the field edges are not that rich in floral diversity as these are mainly for erosion control, particularly on sloping land and the flora is dominated by grass species that do not support parasitoid populations. A possible intervention under these circumstances would be the introduction of flowering plant species in the edges to promote the activity of parasitoid species, as suggested by Gourdine *et al*. (2003).

Field surveys showed that despite the extensive use of insecticides on both smallholder and large scale farms, there are also active parasitoids of DBM and other brassica insect pests. The challenge therefore is to tip the balance in favour of biological control. In smallholder farms, there is potential for the implementation of conservation biological control by increasing floral diversity in brassica fields. This in turn may lead to increased faunal activity that may support predatory and parasitoid species. For the large scale farmers, there is scope for the reduction in pesticide use and a shift towards the use of benign pesticides that are more selective and less toxic to natural enemies (Akol *et al*., 2002). There is also need for work on establishing control threshold levels not only for DBM but also other lepidopteran pests.

CHAPTER 4

SUSCEPTIBILITY OF BRASSICA VARIETIES TO DBM INFESTATION AND THE IMPACT OF INTERCROPPING CABBAGE WITH INDIAN MUSTARD (*BRASSICA JUNCEA*) ON THE INCIDENCE OF DBM

Introduction

Smallholder and large scale horticultural farmers in Zimbabwe grow a diverse range of brassicas targeting different market niches. Smallholder farmers mainly grow rape, covo, cabbage, Indian mustard (*Brassica juncea*) and Ethiopian mustard (*Brassica carinata*) while the large scale farmers mainly grow cabbage, rape, cauliflower and broccoli (Jackson, 1997; Dobson *et al*., 2002). In a study of the two major horticultural provinces of Zimbabwe in 1988, Jackson (1997) noted that the smallholder farmers grew a combined hectarage of 1,006 ha for rape, 425 for cabbage, 177 for covo and 73 ha for *Brassica juncea*. This area under brassicas constituted about 36% of the total area cultivated under vegetables by smallholders in the Mashonaland East and Mashonaland West provinces of Zimbabwe (Jackson, 1997).

The management of brassica pests through host plant resistance has environmental and economic advantages compared with the use of synthetic insecticides. Glossy brassica strains are resistant to DBM partly through antibiosis and mortality occurs predominantly during the first instar (Eigenbrode and Shelton, 1992; Ulmer *et al*., 2002). Several cultivated brassicas, notably cabbage (*B. oleracea* var. *capitata*), broccoli (*B. oleracea* var. *italica*) and oilseed rape (*Brassica napus*) have been transformed to express *Bt* genes (Zhao *et al*., 2002; Schuler *et al*., 2004; Cao *et al*., 2005) although so far none of these have been commercialized. Commercial releases of *Bt* brassicas may not

necessarily benefit farmers in developing countries such as Zimbabwe because such varieties may be cost-prohibitive for the farmers.

Diamondback moth adults prefer to oviposit on *Brassica juncea* compared to other brassica varieties and several workers have recommended the use of *Brassica juncea* as a trap crop for adults of various lepidopteran species including DBM (Parker *et al*., 1995; Charleston and Kfir, 2000; Hooks and Johnson, 2003). In Zimbabwe, however, there is no documentation of the incidence of DBM on different brassica types

Studies were conducted at Africa University Farm, Hartzell and Weirmouth farm from August 2007 to April 2009 to document DBM incidence on different brassicas. This information is essential in identifying varieties that are less attractive to DBM that farmers may grow in particular seasons to avoid the high incidence of DBM. The overarching objective of this study was to determine the differences in DBM populations among different brassica types across different cropping seasons as well as to assess the impact of intercropping cabbage (*Brassica oleracea* var. *capitata*) with Indian mustard (*Brassica juncea*) on DBM incidence.

Materials and Methods

Monitoring Seasonal DBM Populations on Covo

A long term field trial on the semi-perennial covo (*Brassica oleracea* var. *acephala*) was established at Africa University farm in July 2007. The field was 20 m long and 15 m wide, with an interrow plant spacing of 45 cm and an intrarow plant spacing of 30 cm. No insecticides were applied on the crop and records of small DBM larvae, large DBM larvae, DBM pupae and *Cotesia pluetellae* cocoons were taken from September 2007 to December 2008. A similar long term field trial was established at

Hartzell Mission in August 2008 on a plot 15 m long and 10 m wide with an interrow plant spacing of 45 cm and an intrarow plant spacing of 30 cm. Records of small DBM larvae, large DBM larvae, DBM pupae and *Cotesia plutellae* cocoons were taken from September 2008 to March 2009.

Monitoring DBM Infestation on Different Brassica Varieties

Field trials were established at Africa University to monitor DBM populations on different brassica varieties. The field plots were arranged in a completely randomized design with three replicates of brassica variety treatments. Separate trials were planted in August 2007, March 2008, May 2008, and February 2009. The brassica varieties used were rape, Ethiopian mustard (*Brassica carinata*), *Brassica juncea*, 'Choumollier' (a non-heading cabbage variety) and two heading cabbage varieties 'Drumhead' and 'Sugarloaf' in the August 2007 trial. Rape, *Brassica carinata*, *Brassica juncea* and 'Sugarloaf' were used in the March 2008 trial. Rape, *Brassica carinata*, *Brassica juncea* and 'Drumhead' were used in the May 2008 and February 2009 trials. Population levels of the cabbage aphid (*Brevicoryne brassicae*) and its parasitoid (*Diaeretiella rapae*) and flea beetle adults (*Phyllotreta* sp.) were also monitored from September to October in 2007.

Crop Management

For each trial, 250 kg/ ha of compound S (7% N, 20% P, 7% K) basal fertilizer was applied on all field plots. For all brassica types, nursery raised seedlings were transplanted into plots (4 m long X 3 m wide) at a spacing of 60 cm between the rows and 40 cm within the rows. A soil drench of Karate® (λ-cyhalothrin) at a dosage of 8 ml per 10 litres of water was applied to control cutworm (*Agrotis* sp.). No insecticides were

applied on the trial plots thereafter. A top dressing of 150 kg/ha of ammonium nitrate (34.5% N) fertilizer was applied at 4 weeks on rape, *Brassica juncea* and *Brassica carinata* and at 8 weeks after transplanting for cabbage.

Intercropping Cabbage with *Brassica juncea*.

Three trials were set up for this experiment. At Africa University, the cabbage Drumhead variety was transplanted in November 2008 and at Weirmouth the cabbage variety Star 3311 was also transplanted in November 2008. A third trial was set up at Weirmouth in February 2009 using the cabbage cultivar Hercules.

The trials were set up in a randomized block design with three treatments as untreated cabbage only, cabbage/*Brassica juncea* intercrop and untreated *Brassica juncea* only. Each plot was 4 m long and 3 m wide. There were three replicates for each treatment. A basal fertilizer application of 250 kg/ ha of compound S (7% N, 20% P, 7% K) was applied on all field plots. For the cabbage only and *Brassica juncea* only treatments, nursery raised seedlings were transplanted at a spacing of 60 cm between rows X 40 cm within rows. In the cabbage/*Brassica juncea* intercrop treatment, a row of *Brassica juncea* was planted in the middle of two cabbage rows spaced 60 cm apart.

A soil drench of Karate® (λ-cyhalothrin) at a dosage of 8 ml per 10 litres of water was applied to control cutworm (*Agrotis* sp.). No insecticides were applied to the trial plots thereafter. A top dressing of 150 kg/ha of ammonium nitrate (34.5%N) fertilizer was applied at 4 weeks after transplanting for the *Brassica juncea* and at 8 weeks after transplanting for the cabbage only and intercropped cabbage.

Field Sampling for Insect Pests in Covo Plots

Sampling for insect pests in the long term covo trial was done at weekly intervals from September 2007 to December 2007, from January 2008 to December 2008 at Africa University. At Hartzell, sampling was also at weekly intervals from September 2008 to December 2008 and from January 2009 to March 2009. A total of 75 plants were randomly sampled per session with 25 plants representing a replicate. DBM larvae, pupae and parasitized larvae were recorded. DBM larvae and pupae were collected and reared in the laboratory to determine parasitism levels in the field as described in Chapter 3.

Sampling for Insect Pests on Different Brassica Varieties

Sampling was done at weekly intervals. DBM larvae, pupae and parasitized larvae were recorded from the three center rows per plot. Eight plants in each row were scouted, making a total of 24 plants per plot. DBM larvae and pupae were collected and reared in the laboratory to determine parasitism levels in the field as described in Chapter 3.

Parasitoid Identification

Parasitoid wasps were identified using taxonomic keys in three texts, namely Scholtz and Holm (1985), Arnett (1997) and Azidah *et al*. (2000).

Data Analysis

Data were analyzed using Minitab® Version 15 (Minitab, 2006). Means of insect population counts were first tested for normality using the Anderson-Darling test. Non-normal data were transformed using the square root transformation [$\sqrt{(x+1)}$] and subjected to one-way ANOVA. Tukey's honest significant difference (HSD) values were used to separate means at the 5 % significance level.

Results

Seasonal DBM Populations on Covo at Africa University

At Africa University, from September 2007 to December 2007, small and large DBM larval populations started to increase in the month of October and reached peaks of 2.83 small larvae and 2.65 large larvae per plant in the second week of November (Table 4.1). The density of *Cotesia plutellae* cocoons reached a peak in the third week of November with 0.75 cocoons per plant (Table 4.1). DBM larval populations started to decline at the end of November. Seasonal mean values indicated significantly more, small and large DBM larvae compared to DBM pupae and *Cotesia plutellae* cocoons (Table 4.1).

From January 2008 to April 2008, DBM larval populations continued to decline and on 50% of the sampling dates, no DBM larvae were recorded (Table 4.2). Seasonal mean values indicated no significant differences in numbers of small larvae, large larvae, pupae and *Cotesia plutellae* cocoons (Table 4.2). In the winter season from May 2008 to August 2008, there were even lower population levels of DBM stages and no *Cotesia plutellae* cocoons were recorded (Table 4.3). During the September 2008 to December 2008 season, there were lower DBM population levels compared to the September 2007 to December 2007 season (Tables 4.1 and 4.4). In September 2008 to December 2008 the peak small larval density was 0.24 larvae per plant in October while the peak large larval density was 0.23 larvae per plant in the same month. During this season there was little *Cotesia plutellae* parasitoid activity (Table 4.4).

Seasonal DBM Populations on Covo at Hartzell

At Hartzell, during the early summer season from September 2008 to December 2008, DBM populations were much higher than at Africa University (Tables 4.4 and 4.5). Large DBM density reached a peak of 1.32 larvae per plant and a small DBM larval density of 0.51 larvae per plant in early October (Table 4.5). Thereafter the population levels started to decline. Seasonal mean values indicated a significantly higher density of large DBM larvae compared to small DBM larvae, DBM pupae and *Cotesia plutellae* cocoons (Table 4.5). In the late summer season, from January 2009 to March 2009, there were low populations of small DBM, large DBM, DBM pupae and *Cotesia* plutellae *cocoons* (Table 4.6).

Seasonal DBM Populations on Brassica Varieties

At Africa University, during the period September 2007 to October 2007, DBM populations reached a peak density on Choumollier at 4.35 large larvae per plant and 2.06 small larvae per plant (Table 4.7). This coincided with a peak density in *Cotesia plutellae* cocoons at 0.18 cocoons per plant on 'Choumollier'. *Brassica carinata* and *Brassica juncea* were not infested by DBM (Table 4.7). 'Choumollier' (an open leaf cabbage variety) had the highest DBM infestation followed by 'Sugarloaf' (a heading cabbage variety), then 'Drumhead' (a heading cabbage variety). Rape was not infested at the same level as 'Choumollier' and the cabbage varieties (Table 4.7). Counts of all DBM stages were lower from April 2008 to May 2008 compared with the period from September 2007 to October 2007 (Tables 4.7 and 4.8). In the April 2008 to May 2008 trial, the Sugarloaf variety supported significantly higher numbers of large DBM larvae, DBM pupae and *Cotesia plutellae* cocoons. In the period June 2008 to July 2008, there were no

significant differences in infestation levels across all the brassica types (Table 4.9). The period March 2009 to April 2009, had low DBM population densities (Table 4.10) but the Drumhead cabbage variety had significantly higher densities for small and large DBM larvae (Table 4.10).

Intercropping Cabbage with *Brassica juncea*

The first trials set up in November 2008 at Weirmouth and Africa University trials were destroyed by bacterial black rot disease (*Xanthomonas campestris* pv. *campestris*), and there was low insect activity during this period and hence no data were available. The second trial at Weirmouth from March 2009 to April 2009 showed that cabbage only and cabbage in intercrop had a significantly higher density of large DBM larvae compared to the *Brassica juncea* only. There was no significant difference in the density of small DBM larvae and large DBM larvae between the cabbage only and the intercropped cabbage (Table 4.11).

Aphid and Flea Beetle Populations on Brassica Varieties

At Africa University, during the period September 2007 to October 2007, aphid density was highest on 'Choumollier' reaching 8.51 colonies per plant at the end of September (Table 4.12). Rape was the second most heavily infested crop with a seasonal mean of 1.69 colonies per plant. *Brassica carinata* and 'Drumhead'were not significantly different from each other (Table 4.12). No aphids were recorded on *Brassica juncea* (Table 4.13). Rape had a significantly higher seasonal aphid parasitoid density with a mean of 0.31 parasitoids per colony (Table 4.13). There were no significant differences in aphid parasitoid density between *Brassica carinata*, 'Choumollier' and 'Drumhead'

(Table 4.13). No aphid parasitoids were recorded on *Brassica juncea* in the field as there were no aphid hosts.

Adult flea beetle counts showed that *Brassica juncea* was the only brassica variety infested by flea beetles, with a seasonal density of 0.52 beetles per plant (Table 4.14). No predators or parasitoids of flea beetles were recorded.

Table 4.1: DBM Life Stages and *Cotesia plutellae* Cocoon Densities on Covo at Africa University from September 2007 to December 2007.

Date	Mean counts per plant (±SE) n=75							
	DBM small larvae		DBM large larvae		DBM pupae		*Cotesia* sp. cocoons	
21 Sept	0.00±0.00	a	0.07±0.01	a	0.09±0.01	b	0.00±0.00	a
28 Sept	0.24±0.05	b	0.00±0.00	a	0.05±0.01	b	0.00±0.00	a
05 Oct	0.00±0.00	a	0.07±0.01	a	0.05±0.01	b	0.00±0.00	a
19 Oct	1.43±0.04	c	1.13±0.08	b	0.05±0.01	b	0.29±0.04	b
26 Oct	2.03±0.01	d	1.03±0.04	b	0.08±0.02	b	0.11±0.01	a
02 Nov	1.64±0.05	c	0.97±0.04	b	0.04±0.00	a	0.13±0.01	a
09 Nov	2.83±0.05	e	2.65±0.23	c	0.04±0.00	a	0.12±0.02	a
16 Nov	1.77±0.06	c	1.91±0.34	d	0.08±0.02	ab	0.75±0.12	c
23 Nov	0.31±0.04	b	0.33±0.04	a	0.05±0.01	ab	0.24±0.02	b
30 Nov	0.00±0.00	a	0.11±0.01	a	0.00±0.00	a	0.07±0.01	a
07 Dec	0.07±0.01	a	0.07±0.01	a	0.00±0.00	a	0.00±0.00	a
14 Dec	0.04±0.02	a	0.35±0.05	a	0.00±0.00	a	0.00±0.00	a
21 Dec	0.05±0.01	a	0.19±0.01	a	0.01±0.01	a	0.09±0.01	a
28 Dec	0.12±0.06	a	0.28±0.06	a	0.01±0.01	a	0.13±0.27	a
Seasonal mean	0.75±0.15	A	0.65±0.12	A	0.04±0.01	B	0.14±0.03	B

Means in a column followed by the same lowercase letter are not significantly different (Tukey's HSD, α=0.05).
Means in a row followed by the same uppercase letter are not significantly different (Tukey's HSD, α=0.05).

Table 4.2: DBM Life Stages and *Cotesia plutellae* Cocoon Densities on Covo at Africa University from January 2008 to April 2008.

Date	Mean counts per plant (±SE) n=75							
	DBM small larvae		DBM large larvae		DBM pupae		*Cotesia* sp. cocoons	
04 Jan	0.11±0.07	a	0.16±0.06	a	0.00±0.00	a	0.01±0.01	a
11 Jan	0.00±0.00	b	0.00±0.00	b	0.00±0.00	a	0.05±0.01	b
18 Jan	0.00±0.00	b	0.03±0.01	b	0.03±0.01	ab	0.00±0.00	c
25 Jan	0.01±0.01	b	0.01±0.01	b	0.00±0.00	a	0.01±0.01	c
01 Feb	0.00±0.00	b	0.04±0.00	b	0.00±0.00	a	0.00±0.00	c
08 Feb	0.04±0.00	b	0.04±0.00	b	0.01±0.01	a	0.01±0.01	c
15 Feb	0.08±0.00	a	0.11±0.01	c	0.03±0.01	ab	0.00±0.00	c
22 Feb	0.00±0.00	b	0.04±0.00	b	0.05±0.01	ab	0.01±0.01	c
29 Feb	0.01±0.01	b	0.00±0.00	b	0.00±0.00	a	0.03±0.01	c
07 Mar	0.04±0.00	b	0.03±0.01	b	0.00±0.00	a	0.00±0.00	c
14 Mar	0.07±0.01	ab	0.00±0.00	b	0.00±0.00	a	0.00±0.00	c
21 Mar	0.00±0.00	b	0.00±0.00	b	0.01±0.01	a	0.03±0.01	c
28 Mar	0.00±0.00	b	0.00±0.00	b	0.00±0.00	a	0.00±0.00	c
04 Apr	0.00±0.00	b	0.00±0.00	b	0.00±0.00	a	0.00±0.00	c
11 Apr	0.01±0.01	b	0.01±0.01	b	0.01±0.01	a	0.00±0.00	c
18 Apr	0.03±0.03	b	0.00±0.00	b	0.01±0.01	a	0.00±0.00	c
25 Apr	0.00±0.00	b	0.00±0.00	b	0.03±0.01	a	0.00±0.00	c
Seasonal mean	0.03±0.01	A	0.03±0.01	A	0.01±0.01	A	0.02±0.02	A

Means in a column followed by the same lowercase letter are not significantly different (Tukey's HSD, α=0.05).
Means in a row followed by the same uppercase letter are not significantly different (Tukey's HSD, α=0.05).

Table 4.3: DBM Life Stage Densities on Covo at Africa University from May 2008 to August 2008.

Date	Mean counts per plant (±SE)[1] n=75					
	DBM small larvae		DBM large larvae		DBM pupae	
02 May	0.00±0.00	a	0.00±0.00	a	0.02±0.02	a
09 May	0.01±0.01	a	0.00±0.00	a	0.00±0.00	a
16 May	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
23 May	0.00±0.00	a	0.03±0.02	a	0.00±0.00	a
30 May	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
06 Jun	0.00±0.00	a	0.03±0.02	a	0.02±0.02	a
13 Jun	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
20 Jun	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
27 Jun	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
04 Jul	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
11 Jul	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
18 Jul	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
25 Jul	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
01 Aug	0.03±0.03	a	0.02±0.02	a	0.02±0.02	a
08 Aug	0.03±0.01	a	0.02±0.02	a	0.02±0.02	a
15 Aug	0.00±0.00	a	0.00±0.00	a	0.02±0.02	a
22 Aug	0.01±0.01	a	0.00±0.00	a	0.00±0.00	a
29 Aug	0.01±0.01	a	0.02±0.02	a	0.00±0.00	a
Seasonal mean	0.01±0.01	A	0.01±0.02	A	0.01±0.02	A

Means in a column followed by the same lowercase letter are not significantly different (Tukey's HSD, α=0.05).
Means in a row followed by the same uppercase letter are not significantly different (Tukey's HSD, α=0.05).
[1]= No *Cotesia plutellae* cocoons were recorded.

Table 4.4: DBM Life Stages and *Cotesia plutellae* Cocoon Densities on Covo at Africa University from September 2008 to December 2008.

Date	Mean counts per plant (±SE) n=75							
	DBM small larvae		DBM large larvae		DBM pupae		*Cotesia* sp. cocoons	
05 Sept	0.00±0.00	a	0.02±0.02	a	0.00±0.00	a	0.00±0.00	a
12 Sept	0.04±0.03	ab	0.07±0.04	a	0.00±0.00	a	0.00±0.00	a
19 Sept	0.03±0.03	ab	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
26 Sept	0.08±0.00	ab	0.04±0.03	a	0.00±0.00	a	0.00±0.00	a
03 Oct	0.09±0.05	c	0.03±0.03	a	0.00±0.00	a	0.02±0.02	a
10 Oct	0.04±0.00	a	0.20±0.03	b	0.00±0.00	a	0.00±0.00	a
17 Oct	0.24±0.03	b	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
24 Oct	0.05±0.02	b	0.12±0.00	b	0.00±0.00	a	0.00±0.00	a
31 Oct	0.12±0.00	b	0.23±0.05	b	0.00±0.00	a	0.00±0.00	a
07 Nov	0.15±0.03	a	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
14 Nov	0.09±0.03	ab	0.22±0.04	b	0.08±0.03	b	0.00±0.00	a
21 Nov	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
28 Nov	0.05±0.03	a	0.13±0.02	b	0.00±0.00	a	0.03±0.03	a
05 Dec	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
12 Dec	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
Mean	0.07±0.01	A	0.07±0.02	A	0.01±0.01	B	0.01±0.01	B

Means in a column followed by the same lowercase letter are not significantly different (Tukey's HSD, α=0.05).
Means in a row followed by the same uppercase letter are not significantly different (Tukey's HSD, α=0.05).

Table 4.5: DBM Life Stages and *Cotesia plutellae* Cocoon Densities on Covo at Hartzell from September 2008 to December 2008.

Date	Mean counts per plant (±SE) n=75							
	DBM small larvae		DBM large larvae		DBM pupae		*Cotesia* sp. cocoons	
26 Sept	0.39±0.03	a	0.15±0.03	a	0.04±0.04	a	0.02±0.02	a
03 Oct	0.51±0.09	a	1.32±0.05	b	0.45±0.08	b	0.00±0.00	a
10 Oct	0.17±0.04	b	0.31±0.04	c	0.08±0.02	a	0.02±0.02	a
17 Oct	0.08±0.03	bc	0.06±0.02	d	0.08±0.02	a	0.09±0.02	b
24 Oct	0.15±0.04	b	0.39±0.04	c	0.05±0.02	a	0.00±0.00	a
31 Oct	0.07±0.03	b	0.43±0.02	c	0.15±0.03	a	0.08±0.00	b
07 Nov	0.03±0.02	b	0.12±0.04	d	0.02±0.02	a	0.02±0.02	a
14 Nov	0.00±0.00	c	0.09±0.02	d	0.07±0.02	a	0.00±0.00	a
21 Nov	0.05±0.05	c	0.09±0.06	d	0.00±0.00	a	0.00±0.00	a
28 Nov	0.05±0.02	c	0.17±0.03	d	0.03±0.03	a	0.02±0.02	a
05 Dec	0.00±0.00	c	0.00±0.00	d	0.09±0.03	a	0.09±0.02	b
12 Dec	0.00±0.00	c	0.00±0.00	d	0.04±0.00	a	0.08±0.00	b
Seasonal mean	0.13±0.03	A	0.26±0.06	B	0.09±0.02	A	0.14±0.03	A

Means in a column followed by the same lowercase letter are not significantly different (Tukey's HSD, α=0.05).
Means in a row followed by the same uppercase letter are not significantly different (Tukey's HSD, α=0.05).

Table 4.6: DBM Life Stages and *Cotesia plutellae* Cocoon Densities on Covo at Hartzell from January 2009 to March 2009.

Date	Mean counts per plant (±SE) n=75							
	DBM small larvae		DBM large larvae		DBM pupae		*Cotesia* sp. cocoons	
16 Jan	0.00±0.00	a	0.03±0.03	ab	0.00±0.00	a	0.00±0.00	a
23 Jan	0.02±0.02	a	0.00±0.05	a	0.00±0.00	a	0.00±0.00	a
30 Jan	0.00±0.00	a	0.02±0.04	ab	0.00±0.00	a	0.00±0.00	a
06 Feb	0.00±0.00	a	0.00±0.02	a	0.00±0.00	a	0.00±0.00	a
13 Feb	0.00±0.00	a	0.04±0.04	b	0.00±0.00	a	0.00±0.00	a
19 Feb	0.00±0.00	a	0.04±0.02	b	0.00±0.00	a	0.00±0.00	a
06 Mar	0.02±0.02	a	0.11±0.04	c	0.07±0.04	b	0.04±0.03	b
20 Mar	0.04±0.00	b	0.11±0.02	c	0.02±0.02	b	0.05±0.03	b
27 Mar	0.00±0.00	a	0.00±0.06	a	0.06±0.02	b	0.00±0.00	a
Seasonal mean	0.01±0.01	A	0.04±0.01	B	0.02±0.02	AB	0.01±0.02	A

Means in a column followed by the same lowercase letter are not significantly different (Tukey's HSD, α=0.05).
Means in a row followed by the same uppercase letter are not significantly different (Tukey's HSD, α=0.05).

Table 4.7. DBM Life Stages and *Cotesia plutellae* Cocoon Densities on Brassica Varieties at Africa University Sampled over 5 Weeks from September 2007 to October 2007.

Variety	Mean counts per plant (±SE) n=72							
	DBM small larvae		DBM large larvae		DBM pupae		*Cotesia* sp. cocoons	
Rape	0.05±0.01	a	0.11±0.02	a	0.06±0.01	a	0.00±0.00	a
B. carinata	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
B. juncea	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
Choumollier	2.06±0.43	c	4.35±0.93	c	1.16±0.51	b	0.18±0.06	b
Drumhead	0.13±0.05	a	0.81±0.24	ab	0.16±0.03	a	0.01±0.04	a
Sugarloaf	0.95±0.31	b	1.66±0.51	b	0.27±0.05	a	0.02±0.01	a

Means in a column followed by the same letter are not significantly different (Tukey's HSD, α=0.05).

Table 4.8: DBM Life Stages and *Cotesia plutellae* Cocoon Densities on Brassica Varieties at Africa University Sampled over 8 Weeks from April 2008 to May 2008.

Variety	Mean counts per plant (±SE) n=72							
	DBM small larvae		DBM large larvae		DBM pupae		*Cotesia* sp. cocoons	
Rape	0.02±0.02	a	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
B. carinata	0.01±0.01	a	0.01±0.01	a	0.00±0.00	a	0.00±0.00	a
B. juncea	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
Sugarloaf	0.01±0.01	a	0.03±0.02	b	0.01±0.01	b	0.03±0.01	b

Means in a column followed by the same letter are not significantly different (Tukey's HSD, α=0.05).

Table 4.9: DBM Life Stages and *Cotesia plutellae* Cocoon Densities on Brassica Varieties at Africa University Sampled over 8 Weeks from June 2008 to July 2008.

Variety	Mean counts per plant (±SE) n=72							
	DBM small larvae		DBM large larvae		DBM pupae		*Cotesia* sp. cocoons	
Rape	0.01±0.01	a	0.01±0.01	a	0.00±0.00	a	0.00±0.00	a
B. carinata	0.00±0.00	a	0.01±0.01	a	0.00±0.00	a	0.00±0.00	a
B. juncea	0.00±0.00	a	0.01±0.01	a	0.00±0.00	a	0.00±0.00	a
Drumhead	0.01±0.01	a	0.01±0.01	a	0.01±0.01	b	0.01±0.01	a

Means in a column followed by the same letter are not significantly different (Tukey's HSD, α=0.05).

Table 4.10: DBM Life Stages and *Cotesia plutellae* Cocoon Densities on Brassica Varieties at Africa University Sampled over 3 Weeks from March 2009 to April 2009.

Variety	Mean counts per plant (±SE) n=72							
	DBM small larvae		DBM large larvae		DBM pupae		*Cotesia* sp. cocoons	
Rape	0.00±0.00	a	0.06±0.02	ab	0.02±0.01	a	0.04±0.01	ab
B. carinata	0.00±0.00	a	0.02±0.01	a	0.00±0.00	a	0.05±0.02	ab
B. juncea	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a	0.00±0.00	a
Drumhead	0.06±0.01	b	0.12±0.01	bc	0.00±0.00	a	0.06±0.03	b

Means in a column followed by the same letter are not significantly different (Tukey's HSD, α=0.05).

Table 4.11: DBM Life Stages and *Cotesia plutellae* Cocoon Densities on Cabbage/ *Brassica juncea* Intercrop at Weirmouth Sampled over 6 Weeks from March 2009 to April 2009.

Variety	Mean counts per plant (±SE)[1] n=75					
	DBM small larvae		DBM large larvae		*Cotesia* sp. cocoons	
Cabbage only	0.03±0.01	ab	0.06±0.02	b	0.03±0.02	b
Cabbage/*B. juncea*	0.04±0.01	b	0.06±0.02	b	0.04±0.02	b
B. juncea only	0.01±0.01	a	0.01±0.01	a	0.00±0.00	a

Means in a column followed by the same letter are not significantly different (Tukey's HSD, α=0.05).
[1] = No DBM pupae were recorded in the field.

Table 4.12: Mean Populations of Aphids on Brassica Varieties at Africa University from September 2007 to October 2007.

Date	Mean aphid colonies per plant (±SE)[1] n=72							
	Rape		*B. carinata*		Choumollier		Drumhead	
06 Sept	0.51±0.17	a	0.07±0.02	a	0.84±0.08	a	0.22±0.04	b
13 Sept	0.41±0.17	a	0.05±0.02	a	2.31±0.17	b	0.67±0.04	d
20 Sept	2.01±0.14	b	0.22±0.04	a	4.17±0.17	c	1.57±0.06	e
27 Sept	2.21±0.06	b	2.03±0.13	b	8.51±0.31	d	0.45±0.04	c
04 Oct	3.27±0.22	c	2.59±0.06	c	0.12±0.02	a	0.09±0.02	a
Seasonal mean	1.69±0.31	B	0.99±0.29	A	3.19±0.81	C	0.60±0.14	A

Means in a column followed by the same lowercase letter are not significantly different (Tukey's HSD, α=0.05).
Means in a row followed by the same uppercase letter are not significantly different (Tukey's HSD, α=0.05).
[1]= No Aphid colonies were recorded on *Brassica juncea* in the field.

Table 4.13: Mean Populations of the Aphid Parasitoid (*Diaeretiella rapae*) on Brassica Varieties at Africa University from September 2007 to October 2007.

Date	Mean aphid parasitoid counts per plant (±SE)[1] n=72							
	Rape		*B. carinata*		Choumollier		Drumhead	
06 Sept	0.00±0.00	a	0.00±0.00	a	0.07±0.07	ab	0.03±0.02	a
13 Sept	0.13±0.13	a	0.00±0.00	a	0.12±0.03	ab	0.05±0.02	ab
20 Sept	0.00±0.00	a	0.00±0.00	a	0.15±0.05	b	0.19±0.04	c
27 Sept	0.45±0.11	b	0.00±0.00	a	0.35±0.04	c	0.11±0.02	b
04 Oct	0.96±0.06	c	0.03±0.02	b	0.00±0.00	a	0.00±0.00	a
Seasonal mean	0.31±0.11	A	0.01±0.01	B	0.14±0.03	B	0.08±0.02	B

Means in a column followed by the same lowercase letter are not significantly different (Tukey's HSD, α=0.05).
Means in a row followed by the same uppercase letter are not significantly different (Tukey's HSD, α=0.05).

[1]= No aphid parasitoids were recorded on *Brassica juncea* in the field as there were no aphid hosts.

Table 4.14: Mean populations of flea beetle adults (*Phyllotreta* sp.) on *Brassica juncea* at Africa University from September 2007 to October 2007.

Date	Mean flea beetle counts per plant (±SE)[1] n=72	
	B. juncea	
06 September	0.36±0.11	ab
13 September	0.91±0.14	c
20 September	0.64±0.07	bc
27 September	0.24±0.05	a
04 October	0.43±0.05	ab
Seasonal mean	0.52±0.07	

Means in a column followed by the same letter are not significantly different (Tukey's HSD, α=0.05).

[1]= No flea beetle adults were recorded on rape, *Brassica carinata*, 'Choumollier' and 'Drumhead' in the field.

Discussion

At Africa University, peak DBM densities were recorded from September 2007 to December 2007 and *Cotesia plutellae* cocoons reached a peak density in the third week of November. Nofemela and Kfir (2005) recorded a similar pattern of infestation in South Africa. Ideally parasitoids need to be available early in the season to prevent pest numbers from building up. In this study, low parasitoid densities were noted at the beginning of the hot-dry season (September to October of 2007) and this could be because *Cotesia plutellae* does not tolerate cold temperatures of the winter season (May to July) preceding the hot-dry season.

Cotesia plutellae is known to be more effective in warm lowland regions (Talekar and Shelton, 1993; Parker *et al*., 1995; Safraz *et al*., 2005). The challenge therefore is to devise strategies that support and enhance early dry season on-farm parasitoid populations to minimize the lag between the peak DBM populations and the peak in the parasitoid population. DBM larval populations started to decline at the end of November and this coincided with an increase in rainfall activity (Appendix B). Several workers have documented the impact of rainfall in decreasing DBM populations in brassica fields. Kfir (2003b) noted that epizootics of *Zoopthora radicans* in DBM populations often followed periods of prolonged soft rain.

As from January 2008 to April 2008, DBM larval populations continued to decline and in the winter season from May 2008 to August 2008, there were even lower populations of DBM and no *Cotesia plutellae* cocoons were recorded. Nofemela and Kfir (2005) reported a similar trend in South Africa which has similar climatic conditions to

Zimbabwe. The DBM population decline beginning in January can be attributed to continued rainfall activity, while the low DBM and parasitoid densities in the winter may be a result of cold temperatures. During the September 2008 to December 2008 season, there were lower DBM population levels compared to the September 2007 to December 2007 season. Such an observation is consistent with work on insect ecology. It is often difficult to establish trends in insect populations because of huge seasonal variations induced by unknown natural factors.

At Hartzell, during the early summer season from September 2008 to December 2008, DBM populations were higher than at Africa University. The fact that such differences were observed between two sites that are separated by a distance of 2 km is an indication that insect population parameters are heavily influenced by localized conditions.

At Africa University, during the period September 2007 to October 2007, DBM populations reached a peak density on Choumollier at 4.35 large larvae per plant and 2.06 small larvae per plant. These DBM population levels are consistent with population levels noted in similar studies in the Southern Africa region as well as in East Africa (Nofemela and Kfir, 2005; Löhr *et al*., 2007). 'Choumollier' (an open leaf cabbage variety) had the highest DBM infestation followed by 'Sugarloaf' (a heading cabbage variety), then 'Drumhead' (a heading cabbage variety). Diamondback moth infestation on rape was less than on 'Choumollier' and the cabbage varieties. No DBM life stages were sampled on *Brassica carinata* and *Brassica juncea*. Ayalew and Ogol (2006) also noted that DBM infested cabbage when compared to Ethiopian mustard (*Brassica carinata*). In

the peak winter period from June 2008 to July 2008, there were no significant differences in infestation levels across the brassica types. The period March 2009 to April 2009 had overall low DBM population densities but 'Drumhead' supported significantly higher populations of small and large DBM. This period coincided with the end of the rainy season (Appendix B). Overall, results from the brassica susceptibility trials showed that cabbage varieties had higher levels of DBM infestation compared to other brassica types. These results indicate that it is advisable for farmers to switch to brassica types such as *Brassica juncea* and *Brassica carinata* at the beginning of the hot-dry season to avoid incurring losses due to DBM damage.

Several workers have recommended the use of *Brassica juncea* as a trap crop for various lepidopteran pests including DBM (Parker *et al*., 1995; Charleston and Kfir, 2000). In the current study however, the evidence indicates that *B. juncea* was not effective in attracting DBM when intercropped with cabbage. The results showed that cabbage alone and cabbage in intercrop had a significantly higher density of large DBM larvae compared to the *Brassica juncea* alone. There was no significant difference in the density of small DBM larvae and large DBM larvae between the cabbage alone and the intercropped cabbage.

Although data were collected from only one set of trials, results from concurrent trials on the susceptibility of different brassicas to DBM infestation also showed that DBM did not thrive on *Brassica juncea*. Studies by Ayalew and Ogol (2006) in Ethiopia also showed higher DBM infestation on cabbage and kale (covo) compared to Ethiopian mustard (*Brassica carinata*). Basing on results from the current study, *Brassica juncea*

cannot be recommended as a trap crop for DBM in cabbage fields. In general, studies on the impact of intercropping have in many cases yielded inconclusive or conflicting results. There is also a possibility that the mustard variety used may play an important role and this warrants further investigation.

Studies by Sibanda *et al*. (2000) in Zimbabwe showed that smallholder farmers ranked aphids as the major insect pest of rape. Results from the current study showed that aphid density was significantly higher on Choumollier when compared to rape which was the second most heavily infested brassica. *Brassica carinata* and the Drumhead cabbage variety were not significantly different from each other and no aphids were recorded on *Brassica juncea*. Rape supported a significantly higher parasitoid density than other varieties. Flea beetles are an important pest of *Brassica juncea* as noted in field studies at Africa University where flea beetle counts showed heavy infestations on *Brassica juncea*. The absence of flea beetle predators and parasitoids was also noted by Shepard *et al*. (1999) in South East Asia.

In as much as DBM is the major pest of brassicas, results from this study show that brassica pest management practices also need to take into consideration the control of other brassica pests, particularly aphids and flea beetles. The fact that aphids and flea beetles infested rape and *Brassica juncea*, respectively, makes it easier for farmers to avoid these brassica varieties in areas where these pests are prevalent.

CHAPTER 5

EFFICACY OF THE ENTOMOPATHOGEN *ZOOPHTHORA RADICANS* AGAINST LEPIDOPTERAN LARVAE *IN VITRO*

Introduction

The use of microbes in pest control is an important aspect of IPM in many cropping situations. Fungal and bacterial pathogens have been successfully used for many years with the bacterium *Bacillus thuringiensis* being the most prominent and commercialized because of its ease in production and effectiveness against different insect pests (Tanada and Kaya, 1993). The entomopathogen *Zoophthora radicans* (Brefeld) Batko belongs to the fungal division Eumycota, subdivision Zygomycotina, class Zygomycetes, and order Entomophthorales (Tanada and Kaya, 1993).

The fungus has not been widely exploited in the control of DBM for various reasons. The primary reason is that entomopathogens are highly susceptible to dry conditions and hence efficacy may be low under hot tropical conditions. Nonetheless, the fungus is an important regulating agent in insect populations and can spread rapidly through a population causing extensive mortality, especially when the host insect populations are high (Shepard *et al.*, 1999; Safraz *et al.*, 2005).

Zoophthora radicans infects DBM larvae, pupae and adults. It forms an extensive flat mat of external hyphae which grows out from both sides of the host. Numerous white spores are formed on, and ejected from this mat (Shepard *et al.*, 1999). The fungus can cause dramatic epizootics in *P. xylostella* populations, especially in moist upland areas of the tropics where infection can approach 100% in the field. *Z. radicans* can also infect other lepidopteran species and cabbage aphids besides the diamondback moth (Shepard *et*

al., 1999; Walter *et al*., 2003). The large amount of fungal spores produced during natural epizootics in brassica fields represents a valuable resource as large quantities of diseased cadavers can be harvested from the field and stored for future use. This is more pertinent for a fungus such as *Zoophthora* sp. which is difficult and expensive to grow on artificial media.

The potential of various entomopathogens as biological control agents has been tested for DBM management, but few studies have demonstrated their efficacy under field conditions (Kim *et al*., 2002; Sarfraz *et al*., 2005). In the current study, *Zoophthora radicans* and selected synthetic insecticides were tested for their impact on different lepidopteran larvae and two parasitoid species. The overarching objective of this experiment was to evaluate the efficacy of *Zoophthora radicans* against a range of lepidopteran larvae *in vitro* and also its impact on parasitoid emergence from aphid mummies and *Cotesia plutellae* cocoons.

Materials and Methods

Maintenance of DBM and *Cotesia plutellae* Parasitoid Cultures

A densely planted stand of covo was used to maintain a field culture of diamondback moth at Africa University from where larvae or pupae were collected when required for laboratory experiments. In the laboratory, DBM larvae were reared according to the protocol developed by the Asian Vegetable Research and Development Centre (AVRDC, 1997) on a natural diet of covo (*Brassica oleracea* var. *acephala*) at a temperature of $24^0C \pm 2^0C$. For *Cotesia plutellae*, cocoons were collected from the same covo crop at Africa University and placed in Perspex® vials and held at a room

temperature of $24^0C \pm 2^0C$, and 16:8 (L:D) hour photoperiod. Adults were fed on 20% sugar/water solution in a polythene gauze cage and were used when required in laboratory experiments.

Field Sampling for Diseased Larvae

During field scouting, records of fungal infection on DBM larvae were taken at Africa University farm. Diseased larvae were taken to the laboratory in plastic Perspex® cups and stored in a freezer at 0^0C. For purposes of fungus identification, diseased larvae were viewed under a stereo-microscope to determine the fungus habit characters. Fungal spores were mounted on glass slides and viewed under a compound microscope to determine spore morphology.

Preparation of Fungal Spore Suspension

Field collected DBM cadavers were air-dried at about 27^0C. To prepare a fungal spore suspension, dried cadavers were gently macerated in a mortar using a pestle. The resultant coarse powder was mixed with sterile distilled water to form a liquid suspension. The suspension was strained through three layers of cheesecloth to remove large particles. The concentration of fungal spores was measured using a haemocytometer and was adjusted to about $1.0X10^6$ conidia/ml. This spore concentration had been determined from other studies (Hua and Feng, 2005) to be optimum for DBM infection in laboratory studies.

Preparation of Pesticide Stock Solutions

Pesticide stock solutions were prepared at the recommended field rates for Dimethoate 40 EC (8 ml a.i./10 litres of water), Carbaryl 85 % WP (17 g a.i./10 l),

Malathion 25 % WP (5 g a.i./10 l) and Malathion 50 EC (10 ml a.i./10 l). Sterile distilled water was used as the control. The spore suspension of *Zoophthora radicans* had a concentration of approximately $1.0X10^6$ conidia/ml of sterile distilled water and this was adjusted using a haemocytometer. DBM larvae and pupae, *Helicoverpa armigera* larvae, cabbage looper larvae (*Trichoplusia ni*), webworm larvae (*Hellula undalis*) and cabbage moth larvae (*Crocidolomia* sp.) for the bioassays were collected from the Africa University horticulture section and Weirmouth farm in December 2008.

Bioassays

The leaf residue bioassay procedure described by Kim *et al*. (2002) was used. Covo leaf discs (7 cm diameter) were dipped in sterile distilled water, Carbaryl, Dimethoate, Malathion 25% WP and Malathion 50% EC stock solutions for 10 s in each concentration, held vertically using a pair of forceps to allow excess solution to drip off, and placed on a tray in a laminar hood to dry for 2 h. After the surfaces of the leaf disks were dried, each leaf disc was placed in a glass Petri dish (9 cm diameter) on top of two layers of moistened Whatman® filter paper.

In each Petri dish, individual larvae of small DBM, large DBM, cabbage looper (*Trichoplusia ni*), *Helicoverpa armigera*, webworm (*Hellula undalis*) and cabbage moth (*Crocidolomia* sp.) were placed on the leaf discs, using a clean camel hair brush. There were three replicates per treatment with ten larvae of each species per replicate. Larval mortality was recorded every 24 hours for up to six days. The leaf area consumed by each larva was measured at the end of the experiment, using grid paper and cabbage looper equivalence (CLE) values were derived by dividing the leaf area consumed by non-

parasitized test larvae (X) divided by the leaf area consumed by non-parasitized cabbage looper larvae (Greene, 1972).

In order to determine adult emergence of *Diaeretiella rapae*, DBM and *Cotesia plutellae* from pesticide treated cocoons, a hand held sprayer with a hollow cone nozzle was used to spray the pesticide solutions and the spore suspension onto cocoons laid on Whatman® filter paper in glass Petri dishes. Ten cocoons were placed in each Petri dish with a total of twenty replicates per insect species.

Data Analysis

All data were analysed using Minitab® Version 15 (Minitab, 2006). Normality was tested using the Anderson-Darling test. The percentage mortality data for each pesticide was first transformed to arcsine values and subjected to one-way ANOVA. Data on leaf area consumed by larvae was analyzed for treatment effects, using ANOVA. Treatment means were compared using Tukey's honest significant difference (HSD) at the 5% probability level.

Results

Small DBM larvae (1^{st}-2^{nd} instars) were more susceptible to infection by *Zoophthora radicans* when compared to the large DBM larvae (3^{rd}-4^{th} instars). A mortality rate of 98.68% for small larvae was recorded in comparison to a mortality rate of 21.34% for large DBM larvae (Table 5.1). The fungus had no effect on larvae of *H. armigera* and cabbage looper (Table 5.1). The insecticides Malathion 25 WP and Malathion 50 EC achieved 100% mortality of DBM, cabbage lopper and *H. armigera* larvae (Table 5.1). Dimethoate and Carbaryl were not effective against small and large

DBM larvae, but both insecticides were effective against *H. armigera* larvae and cabbage looper larvae (Table 5.1).

Small DBM larvae treated with *Z. radicans* consumed a significantly lower ($p<0.05$) leaf area of covo when compared to the control. There were no significant differences in the leaf area consumed by large DBM larvae, cabbage looper larvae and *H. armigera* larvae on leaf discs treated with *Z. radicans* and the control (Table 5.2). On leaf disks treated with Malathion 25 WP and Malathion 50 EC, larvae of all species died without consuming any leaf area (Table 5.2). Small DBM larvae and large DBM larvae continued to feed on leaf discs treated with Dimethoate and Carbaryl insecticides (Table 5.2). Larvae of cabbage looper and *H. armigera* on leaf discs treated with Dimethoate and Carbaryl died without consuming any leaf area (Table 5.2.).

Zoophthora radicans had no adverse impact on the time to adult emergence of the aphid parasitoid from aphid mummies, *Cotesia plutellae* adults from cocoons and DBM adults from DBM pupae (Table 5.3). *Zoophthora radicans* did not have a significant impact on the overall percentage emergence of the aphid parasitoids from aphid mummies, *Cotesia plutellae* adults from cocoons and DBM adults from DBM pupae (Table 5.4) as these were not significantly different ($p> 0.05$) from the control.

Non-parasitized early instar larvae of the cabbage looper consumed a significantly higher ($p< 0.05$) leaf area of 27.59 cm^2 compared to the other macro-lepidoptera such as cabbage webworm, cabbage moth and *Helicoverpa armigera* which consumed 13.71 cm^2, 13.07 cm^2 and 14.47 cm^2 respectively (Table 5.5). Non-parasitized neonate DBM larvae consumed an average leaf area of 2.16 cm^2 (Table 5.5). There was a significantly

higher ($p< 0.05$) leaf area consumed by non-parasitized cabbage moth larvae compared to parasitized larvae. There was also a significantly higher ($p< 0.05$) leaf area consumed by non-parasitized *H. armigera* larvae compared to parasitized *Helicoverpa armigera* larvae (Table 5.5). There was no significant difference in the leaf area consumed by parasitized larvae of cabbage moth, *H. armigera* and DBM (Table 5.5). The cabbage looper equivalence (CLE) values were 0.50 for webworm, 0.48 for cabbage moth, 0.53 for *H. armigera* and 0.08 for DBM (Table 5.5).

Table 5.1: Percentage Mortality of Lepidopteran Larvae 6 Days After Insecticide Treatment.

Insecticide	% Mortality (±SE) n=30							
	small DBM		large DBM		Cabbage looper		*Helicoverpa armigera*	
H_2O (control)	0.0±0.0	c	0.0±0.0	c	0.0±0.0	a	0.0±0.0	a
Zoophthora	98.68±0.03	b	21.34±0.07	b	0.0±0.0	a	0.0±0.0	a
Malathion 25	100.0	a	100.0	a	100.0	b	100.0	b
Malathion 50	100.0	a	100.0	a	100.0	b	100.0	b
Dimethoate	0.0±0.0	c	0.0±0.0	c	100.0	b	100.0	b
Carbaryl	0.0±0.0	c	0.0±0.0	c	100.0	b	100.0	b

Means in a column followed by the same letter are not significantly different (Tukey's HSD, α=0.05).

Table 5.2: Mean Leaf Area of Covo Consumed by Lepidopteran Larvae 6 Days After Insecticide Treatment.

Insecticide	Mean leaf area consumed (cm^2±SE) n=30							
	small DBM		large DBM		Cabbage looper		*H. armigera*	
H_2O (control)	2.91±0.03	e	2.28±0.34	c	26.23±0.73	a	26.60±0.12	a
Zoophthora	0.89±0.03	c	1.90±0.07	c	26.77±0.81	a	26.47±0.12	a
Malathion 25	0.00±0.00	a	0.00±0.00	a	0.00±0.00	b	0.00±0.00	b
Malathion 50	0.00±0.00	a	0.00±0.00	a	0.00±0.00	b	0.00±0.00	b
Dimethoate	2.25±0.02	d	1.75±0.04	c	0.00±0.00	b	0.00±0.00	b
Carbaryl	0.48±0.04	b	0.82±0.02	b	0.00±0.00	b	0.00±0.00	b

Means in a column followed by the same letter are not significantly different (Tukey's HSD, α=0.05).

Table 5.3: Impact of Insecticides on Time to Emergence from Pupae for Adults of *Diaeretiella rapae, Cotesia plutelllae* and DBM.

Insecticide	Mean days to emergence (±SE)		
	Aphid mummies n=182	*Cotesia* cocoons n=193	DBM pupae n=187
H_2O (control)	5.2 ± 0.13 a	5.3 ± 0.21 a	4.6 ± 0.16 a
Zoophthora radicans	5.4 ± 0.16 a	5.5 ± 0.17 a	4.9 ± 0.18 a
Malathion 25 WP	0.0 ± 0.00 b	0.0 ± 0.00 b	0.0 ± 0.00 b
Malathion 50 EC	0.0 ± 0.00 b	0.0 ± 0.00 b	0.0 ± 0.00 b
Carbaryl 85 WP	0.0 ± 0.00 b	0.0 ± 0.00 b	0.0 ± 0.00 b
Dimethoate 40 EC	0.0 ± 0.00 b	0.0 ± 0.00 b	5.7 ± 0.26 a

Means in a column followed by the same letter are not significantly different (Tukey's HSD, α=0.05).

Table 5.4. Percentage Emergence of Adults of *Diaeretiella rapae*, *Cotesia plutellae* and DBM 6 Days After Insecticide Treatment of Pupae.

Insecticide	% Emergence from cocoons (± SE)		
	Aphid mummies n=182	*Cotesia* cocoons n=193	DBM pupae n=187
H_2O (control)	99.6±0.14 a	98.7±0.32 a	97.0±0.35 a
Zoophthora radicans	98.3±0.37 a	98.0±0.29 a	98.3±0.19 a
Malathion 25 WP	0.0±0.0 b	0.0±0.0 b	0.0±0.0 b
Malathion 50 EC	0.0±0.0 b	0.0±0.0 b	0.0±0.0 b
Carbaryl 85 WP	0.0±0.0 b	0.0±0.0 b	0.0±0.0 b
Dimethoate 40 EC	0.0±0.0 b	0.0±0.0 b	95.6±0.31 a

Means in a column followed by the same letter are not significantly different (Tukey's HSD, α=0.05).

Table 5.5. Mean Leaf Area Consumed by Non-parasitized Neonate Larvae and Parasitized Early Instar Larvae on Untreated Covo Leaf Discs**.**

Pest species	Mean leaf area consumed (cm^2±SE)		
	Non-parasitized larvae n=30	Parasitized larvae[1] n=15	Cabbage Looper Equivalence[2]
Hellula undalis	13.71±0.49 a	-	0.50
Trichoplusia ni	27.59±1.44 b	-	1.0
Crocidolomia sp.	13.07±0.16 a A	1.36±0.22 a B	0.48
Helicoverpa armigera	14.47±1.75 a A	0.87±0.11 a B	0.53
Plutella xylostella	2.16±0.24 c A	0.88±0.19 a B	0.08

Means in a column followed by the same lowercase letter are not significantly different (Tukey's HSD, α=0.05).
Means in a row followed by the same uppercase letter are not significantly different (Tukey's HSD, α=0.05).

[1] = No parasitized larvae were available.
[2] = The Cabbage Looper Equivalence (CLE) was derived as: Leaf area consumed by test species larva (X) divided by the leaf area consumed by the cabbage looper larva.

Discussion

Entomopathogenic fungi may be an alternative source of insect control agents (Kim *et al*., 2002; Safraz *et al*., 2005). The current study showed that small DBM larvae (1^{st}-2^{nd} instars) were more susceptible to infection by *Zoophthora radicans* when compared to the large DBM larvae (3^{rd}- 4^{th} instars). A mortality rate of 98.68% for small larvae was recorded in comparison to a mortality rate of 21.34% for large DBM larvae. The fungus had no effect on larvae of *H. armigera* and cabbage looper (*Trichoplusia ni*) and this is consistent with reports by other workers (Walter *et al*., 2003; Shah and Pell,

2003) who noted that although *Z. radicans* is considered a species complex, strains isolated from one host species do not usually cross-infect other host species.

Small DBM larvae treated with *Z. radicans* consumed a significantly lower leaf area of covo when compared to the control. There were no significant differences in the leaf area consumed by large DBM larvae, cabbage looper larvae and *H. armigera* larvae on leaf discs treated with *Z. radicans* compared to the control. This observation is because *Z. radicans* acts slowly against larger targets as there is need for a larger spore load to enable the fungus to invade the host and get established (Tanada and Kaya, 1993; Shah and Pell, 2003).

An insect infected by an entomophthorous fungus generally does not display any obvious signs and symptoms at the early stage of infection (Hua and Feng, 2005). Only after the infection has spread within the body does the insect become sluggish or display a nervous restlessness and in many cases it then stops feeding. The period from infection to death of an insect may be as short as 3 days to as long as 12 days depending on the insect species and size, with most deaths occurring at 5 to 8 days. (Tanada and Kaya, 1993; Shah and Pell, 2003; Hua and Feng, 2005).

Zoophthora radicans did not have adverse effects on the emergence of adult aphid parasitoids from mummies, *Cotesia plutellae* adults from cocoons and DBM adults from DBM pupae. The lack of activity of the fungus on the pupal stages can be attributed to the protective effect of the cocoon as well as unsuitable environmental conditions, particularly humidity and temperature which are important in infection and sporulation of *Z. radicans* (Tanada and Kaya, 1993).

The establishment of baseline susceptibility of pest species to insecticides provides vital information required to assess the development of resistance over time and space (Akol *et al*., 2002). Both small DBM larvae and large DBM larvae continued to feed on leaf discs treated with Dimethoate and Carbaryl, but both insecticides were effective against *H. armigera* larvae and cabbage looper larvae. It is not clear as to whether the ineffectiveness of Dimethoate and Carbaryl against DBM larvae was a result of resistance or because the insecticides had no effect on DBM physiology. Dimethoate suppressed the emergence of *Cotesia plutellae* adults from cocoons as well as the cabbage aphid parasitoid from mummies**.**

Outbreaks of *Z. radicans* invariably follow periods of prolonged soft rains. Fungal epizootics depend upon the presence of suitable weather conditions and high host density (Kfir, 2003b). Optimum temperatures for development, pathogenicity and survival for *Z. radicans* fall between 20^0C and 30^0C. High humidity (>90% RH) is required for spore germination and sporulation outside the host and such conditions are usually met during the peak of the rainy season in tropical areas (Shah and Pell, 2003). Field collections of the fungus were recorded in December 2007 and December 2008 only on cabbage at the peak of the rainy season. It is probable that since cabbage has a “closed” canopy, moist humid conditions inside the canopy micro-environment are conducive for fungal proliferation.

Cotesia plutellae is a koinobiont endoparasitoid which lays eggs within a host that continues to grow and be mobile (Wharton, 1993). This aspect is demonstrated in the bioassays where DBM larvae parasitized by *C. plutellae* continued to feed although the

leaf area consumed was significantly less than the leaf area consumed by non-parasitized DBM larvae. In the leaf feeding bioassays there was a significant difference in the leaf area consumed by non-parasitized cabbage moth larvae compared to parasitized larvae. There was also a significant difference in the leaf area consumed by non-parasitized *Helicoverpa armigera* larvae compared to parasitized *H. armigera* larvae. The fact that there was no significant difference in the leaf area consumed by parasitized larvae of cabbage moth, parasitized larvae of *H. armigera* and parasitized DBM larvae could be an indication that the three lepidopteran species are parasitized at the same larval body size. Diamondback moth larvae fed on a leaf area corresponding to a Cabbage Looper Equivalence (CLE) of 0.08. This agrees well with the 0.1 Cabbage Looper Equivalent (CLE) threshold established by Greene (1972) and used by Smith (2003) and Khan *et al*. (2004) in South Carolina as the economic threshold (ET) for DBM on collard greens.

The current study has shown that *Z. radicans* is effective against early instar DBM larvae. It has also been shown that *Z. radicans* does not have adverse impacts on the emergence of *Cotesia plutellae* adults from cocoons and *Diaeretiella rapae* adults from mummies. This is an important consideration in an integrated pest management program where both paraitoids and entomopathogens are used simultaneously.

Despite the positive laboratory results, there are still many hurdles in the full scale use of *Z. radicans* in open fields. The mass production of *Z. radicans* propagules is an expensive process that requires heavy financial investment (Shah and Pell, 2003; Hua and Feng, 2005). For the time being, the promise of using *Z. radicans* lies in natural epizootics that occur following periods of prolonged soft rain as observed by Kfir

(2003b). Perhaps there is need for brassica growers to ensure that fungicides used to control brassica diseases are not detrimental to epizootic spread of *Z. radicans* in DBM populations.

CHAPTER 6

SUMMARY

Brassica production is an important aspect of the horticultural sector in Zimbabwe. The current study investigated several aspects on the ecology and parasitism of DBM on brassicas and results show that despite the extensive use of insecticides on brassica farms, the DBM parasitoid complex is quite diverse although it is dominated by *Cotesia plutellae*. The predominance of *C. plutellae* in DBM parasitism could be because *C. plutellae* thrives under the warm to hot climatic conditions that prevail in much of Zimbabwe's middleveld and highveld regions. Another reason could be that *C. plutellae* is somehow tolerant to insecticides and hence it survives in farming systems where insecticides are used extensively. The occurrence of *Diadegma mollipla* only in the highveld region can be linked to cooler climatic conditions at higher altitudes. The susceptibility of parasitoids *Cotesia plutellae*, *Diadegam mollipla* and *Oomyzus sokolowskii* to conventional and novel insecticides needs to be investigated. This information will be useful in selecting the most appropriate insecticides to use in an IPM program for brassicas.

In Zimbabwe, no threshold levels for DBM control have been established. In Australia and the United states, farmers use a threshold value of 1 DBM larva per plant (Furlong *et al*., 2004). The current study has shown that in early summer (October to November) DBM larval density reached the threshold value of 1 larva per plant and was too high to be adequately controlled by the endoprasitoid *Cotesia plutellae* alone. It is

advisable for farmers to take appropriate DBM control measures during this critical period in order to avoid crop loss.

Studies on unsprayed plots of covo, rape, cabbage, Indian mustard and Ethiopian mustard showed different levels of pest infestation across the various brassicas. Cabbage was heavily infested by DBM while rape was heavily infested by aphids. Flea beetle adults predominantly infested Indian mustard. This information is important for farmers and crop protection practicitioners in selecting brassica varieties to grow in particular seasons and locations with some history of high insect pest pressure. The fungus *Zoophthora radicans* was effective against small DBM larvae *in vitro* and holds some potential in organic production systems where some amount of crop damage is tolerated. There is need to evaluate methods that can enhance its efficacy, particularly when applied under dry field conditions.

The identification of parasitoid specimens in the current study was based entirely on morphological characters and this can be a problem when dealing with cryptic species. New diagnostic techniques such as the analysis of the 16 S gene region of the mitochondrial genome have been used to differentiate cryptic species of *Cotesia* (Rattan *et al*., 2006). A further step from the current study would be to identify the *Cotesia* species in Zimbabwe using molecular techniques such as those used at the International Centre of Insect Physiology and Ecology (ICIPE) in Kenya.

In charting the way forward for brassica pest management in Zimbabwe, the best approach would be to start with farmer training on basic identification and quantification of pest species, identification of beneficial insects and the use of scouting procedures.

Farmers need to adopt conservation biological control (CBC) practices being promoted by Gurr *et al*. (2004) among other workers. CBC involves the modification of the environment or existing practices to protect and enhance specific natural enemies of pest organisms to reduce pest damage. Habitat manipulation to improve natural enemy effectiveness is an achievable goal for smallholder farmers in Zimbabwe and it can be achieved through increased establishment of floral diversity to enhance the efficacy of endemic parasitoids such as *Cotesia plutellae* and other beneficial insects through the provision of prey and shelter as well as sources of pollen and nectar.

For the large scale brassica growers in Zimbabwe, there is potential for the reduction of pesticide induced mortality of natural enemies through better targeting in time and space, reduced frequency of pesticide applications and use of pesticides such as lufenuron, neem and other compounds with a narrow spectrum of activity.

APPENDICES

Appendix A

Map of Zimbabwe Showing Sites for Brassica Field Surveys and Trials Conducted from July 2007 to April 2009.

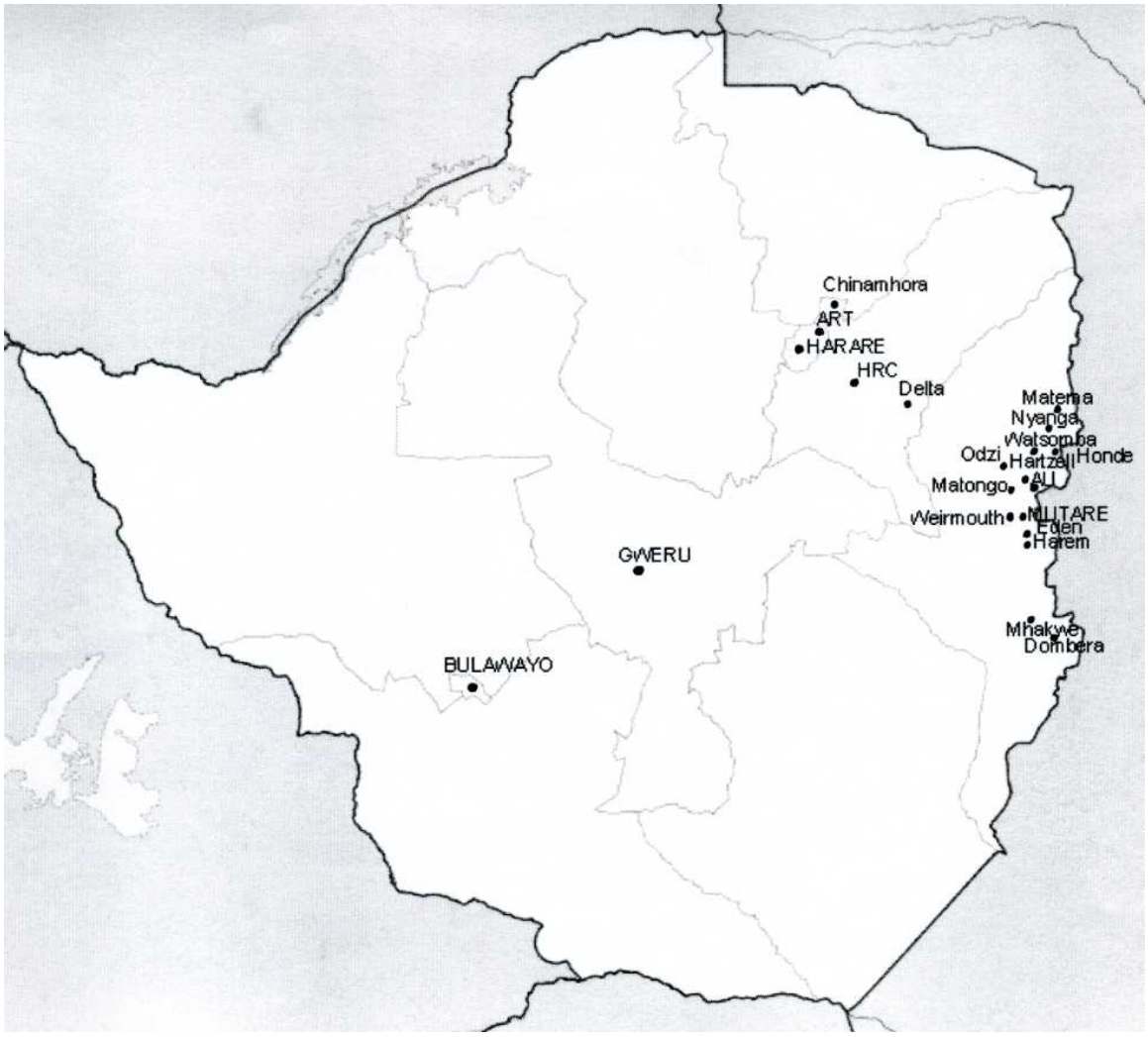

Figure A.1: Map of Zimbabwe Showing Sites for Brassica Field Surveys and Trials Conducted from July 2007 to April 2009.

ART= Agricultural Research Trust Farm
AU = Africa University Campus
HRC= Horticulture Research Centre

Appendix B

Table B.1: Rainfall Data (mm) for Nyanga, Dombera and Africa University in Zimabwe from July 2007 to April 2009.

Month	Nyanga	Dombera	AU
July 07	0	0	0
August	05	0	0
September	0	0	12
October	30	43	12
November	106	125	103
December 07	321	415	471
January 08	297	443	122
February	99	47	34
March	55	24	06
April	07	11	0
May	09	08	0
June	13	12	0
July	12	26	0
August	0	0	0
September	0	0	0
October	29	58	03
November	98	208	14
December 08	391	468	270
January 09	346	488	275
February	118	196	58
March	103	95	83
April 09	68	81	14

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